New Hampshire DOT

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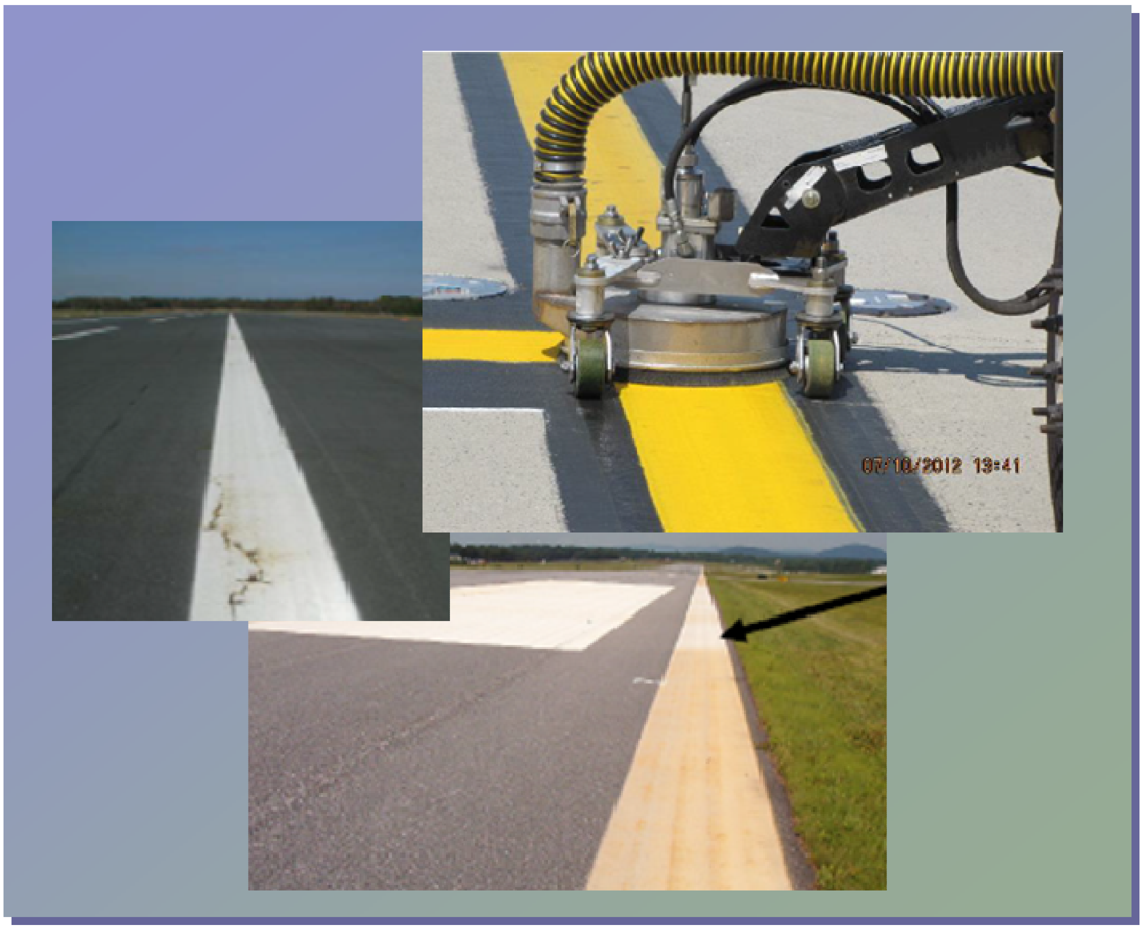

Improve the Quality and Service Life of Water-based Pavement Marking Paints on Pavements with High-Iron Aggregates

Final Report

Prepared by Jacobs Engineering Group Inc. for the
New Hampshire Department of Transportation in cooperation with the
U.S. Department of Transportation, Federal Highway Administration

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7. Author(s)

John Gorham, PE - Jacobs Engineering Group, Inc.

Beran Black, William Real, NHDOT – Bureau of Materials & Research
Carol Niewola, PE, CM, NHDOT – Bureau of Aeronautics
Wallace A. Bothner, Ph.D, David Gress, Ph.D, PE –University of New Hampshire

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Jacobs Engineering Group Inc.
1 Sundial Ave. Suite 410
Manchester, NH, 03103

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16. Abstract

White pavement paint marking on airport runways was being discolored by rust-like staining. Discoloration is a critical safety problem because white paint indicates runways and yellow paint is used for taxiways and aircraft parking. When the white paint is stained it becomes more difficult to distinguish from the yellow paint. This study determined the cause of the discoloration was from the ferrous minerals found in the pavement aggregates.

The study included contacting the industry for methods to extend the service life of pavement paint markings. Water blasting the paint to remove the rust and/or using a modified Federal Specification TT-P-1952E water-borne paint has proven to mitigate the staining. In addition, staining can be reduced by applying a protective coating over the paint; pretreating the asphalt; or using alternative pavement marking materials. Life-cycle cost analyses identified the modified Type III water-borne paint with Type III beads to be the least costly of the proven and potential methods presented.

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Airport surface traffic control, iron oxides, paint, staining, discoloration, airport runways, safety

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Prepared by:
Jacobs Engineering Group Inc.
1 Sundial Ave. Suite 410
Manchester, NH, 03103

Prepared for:
New Hampshire Department of Transportation
Bureau of Materials and Research
Concord, NH

Disclaimer

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The following project team members prepared this report:

Principal Investigator:

Jacobs Engineering Group Inc.

Contributing Authors (listed alphabetically):

Black, Beran NHDOT – Bureau of Materials & Research

Bothner, Wallace A., Ph.D - Professor Emeritus of Geology, University of New Hampshire

Gorham, John, PE - Jacobs Engineering Group, Inc.

Gress, David Ph.D, PE – Professor Emeritus of Civil Engineering, University of New Hampshire

Niewola, Carol, PE, CM, NHDOT – Bureau of Aeronautics

Real, William, NHDOT – Bureau of Materials & Research

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- Sukley, Robin - PADOT
- Vacirca, Cliff - FAA New England District Office
- Villani, Dave – Ennis Flint
- Watkins, Dee - FOL TAPE

Table of Contents

Figures

Tables

EXECUTIVE SUMMARY

The purpose of this study was to 1) positively identify the cause of rust-like staining of pavement paint markings at NH airports; 2) research methods to extend the service life of new or existing markings subject to rust-like staining; and 3) to provide recommendations for additional investigations.

Staining of airfield markings is a safety problem. On airport pavement, white paint markings indicate that the pavement is a runway; yellow paint indicates the pavement is a taxiway or aircraft parking apron. Maintaining this difference in color is critical for the safety of all airport users. Iron, which is present in the sand and stone (aggregate) within the pavement, stains the airfield paint, particularly the white paint. This staining affects compliance with the color standards required by the Federal Aviation Administration (FAA) and Department of Defense (DoD).

Iron staining has occurred within six months to a year of paint application at many New Hampshire (NH) airports[1]. As funds are available, airports correct the staining by repainting or a combination of removal and repainting. Sometimes, it may be years before an airfield repainting project can be funded.

The study components included the completion of several tasks. These tasks included the selection of airports to include in the study; collection of field samples from the selected airports; retrieval of construction material submittal data from the selected airports; laboratory analyses; industry interviews; evaluation of findings; and development of recommendations for additional investigations. A discussion of each element of the study follows:

> Airports were selected for the study based on the prevalence of pavement staining, the availability of construction material submittal data and frequency of painting.
>
> Field sample collection included collection of paint chips and pavement cores from the selected airports.
>
> Laboratory analyses included extraction of the pavement materials; quantifying the percentage of ferrous sand size and smaller materials; elemental analysis of the paint chip staining; petrographic analysis; and an accelerated oxidization test.
>
> Construction material submittal data was collected from previous airport projects, at the selected airports, to attempt to identify the aggregate sources (i.e. quarries), pavement producers, pavement mix designs and paint manufacturers.

[1] Pouliot, Michael. NHDOT, 2011, Project meeting notes.

Industry interviews were conducted with bituminous pavement contractors, painting consultants, paint and material manufacturers and regulatory (State Departments of Transportation and FAA) officials. Interviews collected data on experience with staining, methods to remedy staining, and industry pavement marking products.

Evaluations included compilation of field and laboratory data collected; a review of the field and laboratory data to identify staining trends; material requirements of the FAA P-620 *Runway and Taxiway Marking* paint specification related to staining; a compilation of proven and unproven industry methods; and a life cycle cost comparison of alternative paint materials.

Recommendations for additional investigations to gauge the effectiveness of various alternatives, to identify potential staining sources (i.e. quarries) and improvements to the quality assurance techniques during painting are provided.

The results of each element of the study are summarized below.

The five NH airports selected for the study were Dillant-Hopkins (aka Keene), Claremont, Mount Washington (aka Whitefield), Laconia and Concord. In May and June of 2013, thirty-three paint chips were taken by the University of New Hampshire (UNH) and twenty bituminous pavement cores were collected by the NHDOT.

NHDOT extractions of the pavement cores found the proportions of sand, stone and asphalt generally conform to the FAA bituminous pavement specifications. NHDOT also found a portion of the aggregate smaller than the No. 4 sieve to be attracted to a magnet.

By elemental analysis, UNH found the discoloration on the paint chips to be iron. Ferrous minerals were found in the aggregates UNH included in the petrographic analyses. UNH forced rusting on two samples in a three month, elevated temperature oxidization test.

Agency and industry interviews identified that water blasting the paint to remove rust and/or using a modified Federal Specification TT-P-1952E water-borne paint has proven to mitigate the staining. Potential methods to mitigate the staining such as applying a protective coating over the paint, pretreating the asphalt pavement prior to painting, alternative pavement marking materials and pavement grooving are presented.

Life-cycle cost analyses identified the modified Type III water-borne paint with Type III beads to be the least costly of the proven and potential methods presented.

Recommendations for additional investigations include: field testing and observing over multiple months alternative paint types, sealants and pavement grooving; investigating various aggregate sources to identify the potential for staining; and modifying the FAA P-620 specification to include a modified paint material specification, altering the paint application rate and adding paint thickness measurements, and enhancing record keeping.

I. PROJECT OBJECTIVES

The project had three objectives:

- To positively identify the cause of rust-like staining of pavement paint markings at NH airports,
- To extend the service life of new or existing markings subject to rust-like staining, and
- To provide recommendations for additional studies.

The first project objective, to positively identify the cause of rust-like staining of pavement paint markings at NH airports, was accomplished by the following:

- Breaking down the bituminous pavement surface course into individual sand, stones and asphalt components to compare material composition and potential contributing factors;
- Analyzing paint chips via laboratory testing to identify the presence of iron oxide on the paint surface;
- Conducting petrographic analyses on the pavement aggregate to identify the mineral composition;
- Performing accelerated oxidation testing on sample aggregate to simulate a test of field weathering conditions; and
- Collecting construction submittal data on the paint and pavement materials used, in order to identify possible trends related to stained paint markings.

The second project objective, to determine approaches to extend the service life of new or existing markings subject to rust-like staining, was achieved by conducting interviews and data research provided by federal, state and industry specialists.

The third project objective, to provide recommendations for additional investigations, include: field testing of alternative paint types, pavement seal coats and grooving; identifying aggregate sources that contribute to aggregate staining; and modifications to the FAA P-620 specification.

II. DESCRIPTION OF WORK AND METHODOLOGY

Before describing the work and methodology, an illustration of the paint staining problem is warranted. Staining of paint markings on airport pavement has been noted to occur by two means: over-pavement sheet flow during rain events that carry stains onto the paint markings (Figure 1), and rusting aggregates that create point stains within the pavement markings (Figure 2).

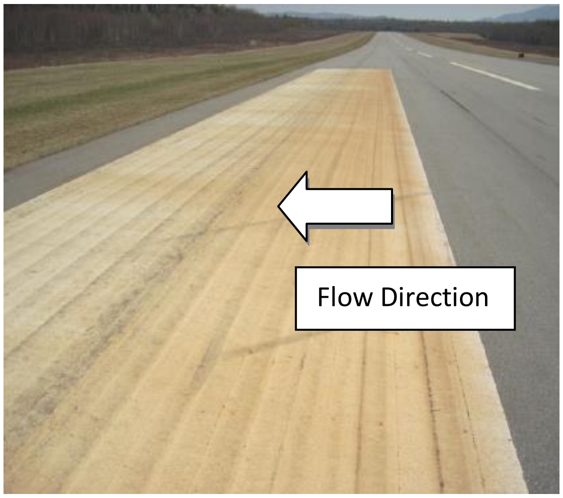

Figure 1 – Sheet flow stains

Figure 2–Point stains (red circles)

Staining of pavement markings has been noted in Florida, Maryland, North Carolina, Georgia, Ohio, and Washington states. The FAA Headquarters; the FAA Atlantic City Technical Center; the FAA's New England, Southern, and Northwest Mountain Regions; and the state Departments of Transportation in New Hampshire (NH), Massachusetts, Maine, and Minnesota have all experienced similar staining[2]. NH airports with iron staining on the pavement markings are located in the towns of Berlin, Whitefield, Laconia, Bristol, Keene, Newport, Twin Mountain, Jaffrey, Claremont, Moultonborough, Errol, and Nashua[3].

The description of the work and methodology is described below by project objective.

Objective 1 – Identify Causes of Rust Staining

The cause of rust staining was determined by selecting the airports to be studied, conducting site visits and sampling materials, performing laboratory tests on the field samples, reviewing existing construction submittal data and reviewing the data for trends related to rust staining.

[2] Black, Beran. NHDOT, 3/2014, Telephone interview notes with FAA, MEDOT, MNDOT & PADOT representatives.

[3] State Planning and Research Project, NHDOT, 2011, Pavement Paint Study, Presentation slides.

Airport Selection

Five of NH's twenty-four airports were included in the study. These five airports were selected based on three primary criteria: 1) the presence of paint staining, 2) the availability of construction submittal material data and 3) airports that did not paint every year. The NH airports selected were: Dillant-Hopkins (aka Keene), Claremont, Mount Washington (aka Whitefield), Laconia and Concord. Refer to Appendix A for Airport Screening Criteria.

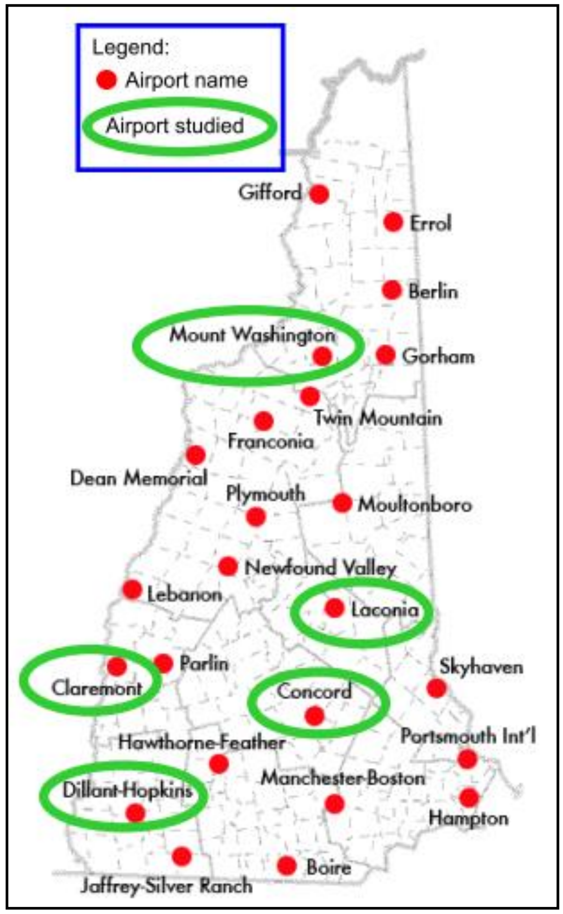

Figure 3 – NH Airports in Study

Site Visits/Material Sampling

In May 2013, the five airports selected were visited to collect paint chip samples and identify pavement sampling locations. In attendance were Dr. David Gress (UNH), Beran Black (NHDOT), Michael Pouliot (NHDOT), and James Murphy (Jacobs). Paint chip samples were chiseled out of the top of the pavement and measured approximately 1-inch square by ¼-inch in depth. UNH retained the paint chips for analysis. Pavement sampling was achieved by coring six-inch +/- diameter samples from the pavements. Cores were collected by NHDOT during May and June of 2013. Appendix B includes the locations chosen for the pavement and paint chip sampling as well as select photographs of the sampling.

NHDOT Laboratory Analyses

After the sampling, the pavement cores were brought back to the NHDOT Materials and Research Laboratory in Concord, NH for further testing. In September 2013, the NHDOT Materials and Research Laboratory extracted, or broke down, the pavement cores into individual stone and sand-size particles. The extraction and gradations were conducted in accordance with ASTM D2172 *"Standard Test Methods for Quantitative Extraction of Bitumen from Bituminous Paving Mixtures".* Extractions were conducted in order to identify the composition of the pavements.

After the pavement cores were extracted, the NHDOT inserted a magnet into the sand size and smaller particles of the sample. The "magnet test" confirmed the presence of iron in the sand aggregate. Figure 4 shows the round pavement cores, the extracted magnetic aggregate. Further discussion of this testing is presented in Section III. The NHDOT laboratory testing results are provided in Appendix C.

Figure 4 - NHDOT Lab – Separated Magnetic Particles

University of New Hampshire Laboratory Analyses

Following NHDOT's lab work, the extracted pavement samples and the remaining whole cores were delivered to UNH's Materials Research Laboratory. The paint chips obtained in the field were examined and photographed use a Scanning Electron Microscope (SEM). Energy Dispersive X-Ray Spectroscopy (EDS) technique was used to perform an elemental analysis on the paint chip stains. This analysis indicated the stains were iron. Further discussion of this testing is presented in Section III.

UNH conducted an oxidation aging test on a sample of the magnetic aggregate to force rusting. UNH conducted petrographic analyses on the extracted aggregates to determine the mineral sources in the aggregates. The UNH report entitled *"Analysis of New Hampshire Airport Pavement Paint Staining"* is provided in Appendix D.

Review of Existing Construction Submittal Data

Where the submittal data was available, NHDOT collected the pavement and paint construction submittal data from the five selected airports. The data was reviewed to identify the manufacturers of the pavement and paint materials, the sources of the aggregates, the bituminous pavement mix design and the construction dates. The submittal data includes numerous pages; therefore in the interest of brevity of this report the construction data has been summarized by airport in Appendix E. Maps showing project locations for each of the five selected airports are included in Appendix E as well.

Staining Trends

The data from the material sampling, the NHDOT and UNH laboratory analyses and the construction submittal data was compiled. The data was reviewed for trends related to staining. The evaluation is discussed in Section IV of this report. The data is tabulated in Appendix F.

Objective 2 – Determine Approaches to Extend the Service Life of Markings

Staining reduces the effectiveness of the paint markings. The time in which the markings are effective, or their "service life", can be reduced by years due to the staining. To identify methods and techniques to manage or reduce staining, industry representatives were contacted. This was accomplished via phone interviews with the FAA, state DOTs, painting consultants and several manufacturers of paint, glass beads, preformed marking tape and bituminous pavement sealants. The effort found the following: 1) the modified paint specification will extend the life of paint exposed to staining; 2) water blasting the stains off the markings has been effective; and 3) other industry methods such as clear coating, seal coating and grooving have the potential to extend the paint life. Section V of this report provides a discussion of these methods. Agency and Industry Telephone Interview notes are provided in Appendix G.

Life-cycle cost analyses were calculated to compare alternative paint materials. The analysis indicated that the lowest cost alternative is the modified Type III paint with Type III beads. The analyses are discussed in Section VI of this report. The Life-Cycle Cost Analyses are provided in Appendix H.

Objective 3 – Recommendations for Additional Investigations

Recommendations for additional investigations were identified during the course of this study. The recommendations include field testing of alternative paint types, evaluation of pavement seal coats and grooving; identifying aggregate sources that potentially contribute to staining aggregates and sources that have a low potential for staining; and potential modifications to the FAA P-620 specification. The recommendations are discussed in Section VIII of this report.

III. PAINT AND PAVEMENT DATA

The project collected thirty-three paint chip samples and twenty pavement cores from the five selected airports. Discussions of the UNH and NHDOT testing are described in the following sections.

NHDOT Laboratory Data

Bituminous Extractions

The NHDOT Materials and Research Laboratory extracted the bitumen from the top layer of the pavement core samples. The aggregate remaining after the extraction was placed on 12 sieves ranging from size 1-1/4 inch down to the No. 200 (0.002 inch ±) smallest sieve. This work was performed to develop the range of aggregate materials, or gradations. The ranges of gradations across the various airport projects are generally uniform, or similar, for each pavement sample. The standard deviation on the sieves from all the samples ranged from 0.5 to 9.8%.

The gradations and asphalt content of the samples were compared to gradations published in the 2014 FAA specification P-401, *Hot Mix Asphalt (HMA) Pavements*. The P-401 specification provides three gradation types. Gradation 2, a ¾" minus gradation, was selected as the basis of comparison to the extraction values as this gradation is typical of the top course of bituminous pavements. Generally, the extraction values are within the P-401 specification range. Whitefield core #4 (2006), Laconia core #2 (2006) and Laconia core #3 (2009) had one to two sieves slightly out of specification range. However, it is noted that the construction of the Whitefield and Laconia pavements precedes the 2014 FAA P-401 specification. It is important to note, the small deviation from the specification has no bearing on the staining characteristics of the aggregate.

Ferrous Content

The NHDOT laboratory developed a test procedure to determine the presence of iron within the portion of extracted materials smaller than the No. 4 sieve (i.e. sand size). A Rare Earth Samarium Cobalt magnet[4] was inserted and 'swirled' within the aggregate material for 15 minutes to collect ferrous materials. The percentage of materials with ferrous content was calculated based on weighing the samples before and after the "magnet test". The difference in before and after weight was the material with ferrous content collected by the magnet. Materials from eleven extractions were tested for ferrous content. A comparison of the source of the aggregate to the percent of iron content is provided in the following table.

[4] Black, Beran. NHDOT, June 11, 2015, Email to S. Dearborn and W. Real with NHDOT.

Quarry - Aggregate Source (No. of Data Points)	Percentage of Aggregates with Ferrous Material Passing No. 4 Sieve
W. Lebanon, NH (3)	3.3% - 10.1% (7.2% Avg.)
Gorham, NH (1)	7.0%
Milan, NH and Gilead, ME (1)	5.5%
Belmont & Hooksett, NH (1)	1.0%
Belmont, NH (1)	2.9%
Londonderry (1)	0.5%

Table 1 - Ferrous Content on No. 4 Sieve and Smaller (NHDOT)

The lower ferrous content is assumed to have a lower potential for staining. Based on this assumption, the data favors the Belmont, Belmont-Hooksett and Londonderry sources, which have the lower iron contents. It is noted that there is no benchmark value to correlate the percentage of iron with the potential for staining. The data above should be used for comparison purposes only.

The NHDOT data is provided in Appendix C.

University of New Hampshire (UNH): SEM, EDS, Petrographic and Oxidation Analyses

The purpose the UNH study was to positively identifying the cause of the paint staining. To accomplish this purpose, field samples of paint chips and cores were obtained for laboratory analysis from five airports. The analysis included the following:

- Photographing paint chips to the microscopic level using a Scanning Electron Microscope (SEM),
- Determining the elements on the paint chips and cores utilizing the Energy Dispersive X-Ray Spectroscopy technique (EDS),
- Conducting petrographic analysis on selected cores of the asphaltic surface mix to identify the type of aggregate used in the pavements, and
- Performing an accelerated aging test on the aggregate containing ferrous materials by oxidation to force rusting.

SEM and EDS

The SEM was used to create a microscopic photograph of the paint chip surface. The SEM creates a three-dimensional visual interpretation by excitation of the sample's electrons. The result is a detailed photograph of the sample. The SEM data provided photographs in a zoom range of 1 millimeter to 10 micrometers. The photograph allowed the investigator to then conduct an elemental analysis of various locations on the paint surface with the EDS technique. A sample photograph is shown in Figure 5.

EDS works by focusing a beam of X-rays into the sample being studied. The X-rays remove an electron from the inner shell of the atom. The electron 'hole' is filled by an outer shell electron. The energy released from the electron movement from the outer to the inner shell is unique to each atom. The number of electrons and energy is measured by an energy-dispersive spectrometer. The spectrometer data is "finger-printed" to a library of elements for identification[5]. A sample EDS elemental analysis output is shown in Figure 6.

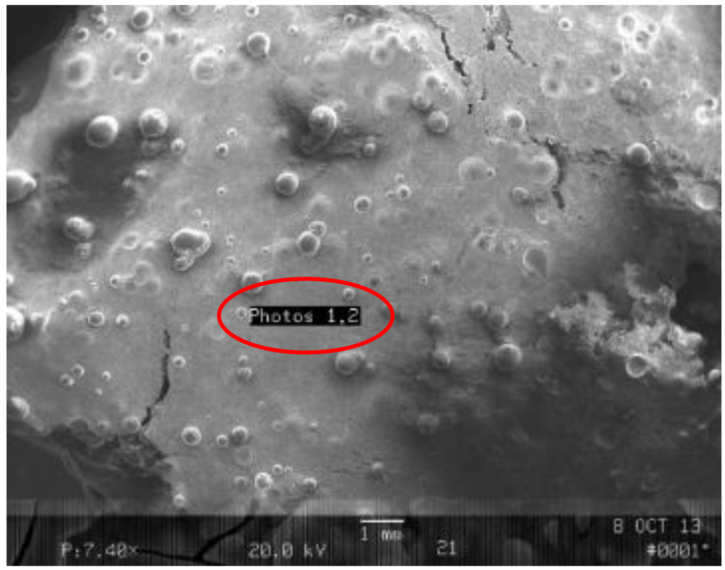

Figure 5 – Sample SEM Photograph of Paint Chip

The SEM and EDS results show that the source of staining is iron at all five airports. As an example, the EDS indicated a higher percentage of iron, greater than 50%, directly over the rust spot located with the SEM. Testing further away from the spot with the EDS, resulted in the percentage of iron decreasing.

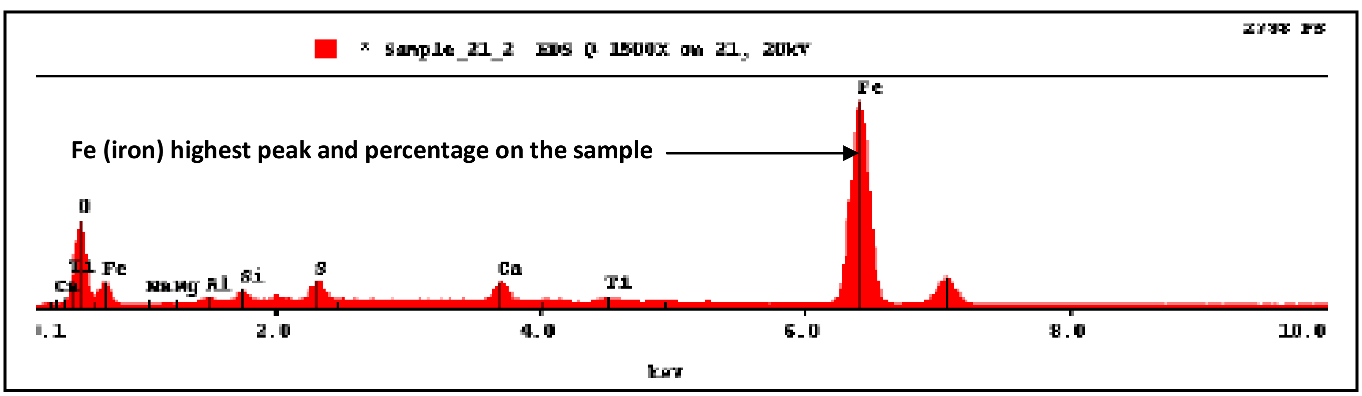

Figure 6 – Sample EDS Elemental Analysis. Fe (iron) highest peak and percentage on the sample.

[5] "Scanning Electron Microscope", Wikipedia, July 2015.

Petrographic Analysis

Petrography is a detailed analysis of minerals by optical mineralogy. Samples are cut in thin sections and viewed in a microscope. The micro-texture and structure are used to understand the origin of the rock. A sample petrographic slide is shown in Figure 7.

Aggregates containing ferrous materials from the airport samples were collected at the NHDOT lab. The aggregates were separated into the coarse (1/2" and larger) and finer aggregate sizes. Coarse aggregates were selected for petrographic analysis based on color, texture, visual crystallinity, grain size and shape.

The aggregate was selected to make sure all possible minerals were included. A total of 38 different aggregate particles from Keene, Whitefield, Concord and Claremont were selected for petrographic analysis.   Laconia was not selected because a previous petrographic analysis was conducted in 2012.

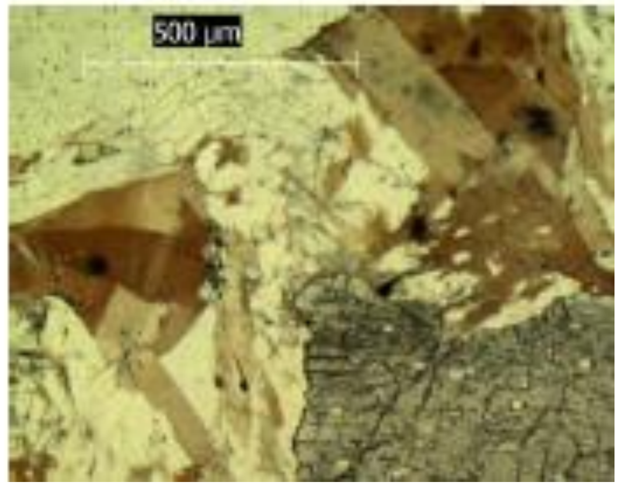

Figure 7 – Sample Petrographic Slide. Color/Mineral: Brown/Biotite, Black/Opaque, Gray/Garnet

The petrographic analyses conducted for this study and the 2012 Laconia study identified primarily metamorphic and igneous materials containing ferrous compounds.

Figure 8- Laboratory Aging Test Rust Stain

Accelerated Aging Test

Smaller magnetic aggregates from each airport were placed in clear epoxy. After the epoxy cured the stone–epoxy matrix was cut into thin disks. The disks were polished using water on a rotating abrasive wheel which resulted in rusting of the aggregate particles at the microscopic level.   The rusting is further evidence of the iron content reported in the petrographic analysis. The observation of rusting during polishing with water led to the development of an accelerated aging test to determine if the magnetic particles could be forced to oxidize under laboratory conditions.

Oxidization is part of the process of weathering or aging of the exposed aggregates. The test consisted of placing the polished epoxy disks of smaller magnetic aggregate (less than 1/2" size) over water for three months at 100° F. The test utilized only the Claremont aggregate as this was a trial exercise.

The test resulted in rust staining. The rust originated in the aggregate then became mobile within the pavement matrix, similar to what happens in the field on the paint markings and the bituminous concrete surface.

The results of the EDS, SEM, petrographic analyses and accelerated aging test are provided in Appendix D.

Construction Submittal Data

The construction submittal data consists of data provided by the contractor that indicates the proposed pavement and paint composition. The composition of pavement materials, commonly referred to as the "mix design", includes the source of the aggregate and asphalt, and the amounts of aggregate and asphalt. A material data sheet indicating the type of paint and the manufacturer of the paint is also typically provided. The contractors submit the pavement and paint data for approval prior to placement of the materials in the project.

The paint study construction submittal data includes airport maps to document the location of the projects. The collected maps included projects between the years of 2002-2009. As these airports existed prior to this date, the information collected did not include all prior airport projects. The available construction data did not cover all the projects shown on the maps. Of the eighteen documented projects, construction data was available for fourteen projects. The construction data includes bituminous pavement mix designs, pavement construction testing reports (e.g. pavement densities and extractions) and paint manufacturer submittal data.

The mix design data identified the year of construction, where the pavement was produced, the source of the aggregate, as well as the asphalt type and target percentage of asphalt used in the pavement. Two paving contractors supplied the pavement for the fourteen projects for which construction data was provided. One supplied pavement for three projects, the other for eleven projects.

While most of the data provided was related to the pavement materials, there were three projects out of the fourteen where paint material data was also available. In these three cases the paint material used was a water-borne product. Two submittals were manufactured by Sherwin Williams and the third was by Franklin Paint.

A summary of this data is provided in Appendix E.

IV. IDENTIFICATION OF TRENDS RESULTING IN PAINT STAINING

The NHDOT laboratory data (extractions and ferrous content), the UNH data, the project construction submittal data and field observations were reviewed to identify staining of paint trends.

Review of the NHDOT extraction data (Appendix C) appears to indicate that the gradation of the aggregate has little bearing on the potential for staining. The gradations are generally similar between pavement suppliers and projects. Additionally, all the pavements for which extraction data was provided exhibited staining of pavement markings.

The ferrous content on the portion of the aggregate finer than the No. 4 sieve (refer to Table 1), provided by NHDOT's "magnet test", indicates that Belmont NH, Hooksett NH, and Londonderry NH source yields the lowest percentages of magnetic materials. The West Lebanon NH, Gorham NH, Milan NH and Gilead ME sources contained higher percentages of magnetic materials. The "magnet test" was developed based on observations in the laboratory. The test does not follow any industry standards (e.g. ASTM). Therefore, there are no benchmark values to correlate the percentages of iron measured with the potential for staining.

The EDS results show high iron (Fe) content in locations on paint chips that are stained. This confirms the staining is rust. The EDS data includes multiple sample points on individual paint chips. The higher Fe percentages were found on the darker stains and lower Fe percentages on the lighter stains. Paint chips were collected from 8 different projects. All 5 airports selected for the study were included. All the paint chips had some level of rust staining.

Figure 9 - Sample Rust Stained Paint Chip

The paint chips analyzed with the EDS were from pavement paint placed over six bituminous pavements with different aggregates. A known source being the pit from which the aggregate used to construct the bituminous pavement is mined and that project submittal data was available. Those sources were W. Lebanon NH, Milan NH, Gilead ME, Gorham NH, Belmont NH, and Hooksett NH. The percentage of Fe from the chips at these six sources varied from 0.7-74.1% (Appendix F). A seventh source, with unknown aggregate source, constructed at Concord had a range of 4.25-15.9% Fe. It is assumed that the source for Concord came from the vicinity of Concord Airport. The paint chip data set is limited to conclude which sources contribute a greater degree to the paint staining. As all the paint chips had some level of Fe measured by the EDS, it can be concluded that each of the seven sources does contribute to the staining. With consideration of location of the sources and the upper range of the Fe percentages, it would appear that the sources from the western (W. Lebanon) and northern (Milan, Gilead, Gorham, Belmont) portions of the state may result in higher Fe percentages and therefore darker staining of the paint. A source from the southern part of the state (assumed Concord area) had a lower iron percentage. This is a qualitative analysis and would have to be confirmed by additional research.

The petrographic analysis found Fe bearing aggregates. Similar to the EDS findings, the petrographic analysis supports the cause of the rust staining as being Fe.

Appendix F includes a Data Summary Table that summarizes the data collected for each airport and selected laboratory results.

V. PRACTICES TO MITIGATE STAINING OF PAVEMENT PAINTS

Removal of Aggregates Causing Staining

Consideration of the removal of the source of the staining, the iron in the aggregate, was researched by contacting two NH bituminous pavement manufacturers, Continental Paving Inc. and Pike Industries Inc. These discussions indicated that the aggregate used in the mix for bituminous pavement comes from various sources throughout NH. According to the suppliers, the removal of the aggregate that causes rust staining would be difficult[6]. This is supported by the petrographic analyses provided in Appendix D. The petrographic analyses note that the aggregates associated with the staining were found to be iron bearing magnetic minerals, very typical of NH aggregates. The FAA has recognized the problem with staining and provided a test to identify aggregates that have a potential for staining.

The FAA's P-401 and P-403 bituminous pavement specifications includes a note to the Engineer regarding staining aggregates. The Engineer's note in the specification states the following:

> *"Some aggregates may contain ferrous sulfides and iron oxides which can cause stains on exposed concrete surfaces. In areas where staining has been a problem or is suspected, the Engineer should verify that producers and aggregate suppliers have taken steps to prevent the inclusion of any ferrous sulfides or iron oxides in aggregate to be used in the project.*
>
> *If there is a concern that these may exist, an indicator to identify staining particles is to immerse the aggregate in a lime slurry. If staining particles are present, a blue-green gelatinous precipitate will form within 5 to 10 minutes, rapidly changing to a brown color on exposure to air and light. The reaction should be*

[6] Black, Beran. NHDOT, 3/2014, Telephone interview notes with NH bituminous concrete suppliers.

complete in 30 minutes. If no brown gelatinous precipitate forms, there is little chance of reaction in concrete[7].”

The lime slurry test recommended by the FAA provides a method to screen aggregate sources during the project’s material approval process. However, as found in the petrographic analyses, the selected NH pavements include iron bearing aggregates. Therefore, the requirement to exclude iron oxide in the aggregate could prove to be difficult for NH bituminous pavement suppliers from NH sources.

Pavement Marking Material and Surface Modifications

Discussions were conducted with individuals from FAA headquarters and regional offices; state DOTs; pavement marking consultants; as well as manufacturers of bituminous pavements, paint, beads and pavement tape in order to identify any and all practices or methods that could be used to mitigate stained airport pavement paint markings. The identified methods are grouped into the categories shown below:

- Proven Methods
    - Water blasting
    - Modification to the paint material specification
- Potential Methods
    - Protective coating under or over the paint
    - Asphalt pre-treatment prior to painting
    - Alternative pavement marking types
    - Pavement grooving

Proven Methods

Rust Removal

There are presently two methods to remove stains from pavement markings, pressure washing and chemical removal.

[7] “Standards for Specifying Construction of Airports”, AC No. 150/5370-10G, Federal Aviation Administration, July 13, 2015, pp. 218 and 258.

Figure 10 - Paint restoration (Speidel, 2008)

Pressure washing uses a pressurized water spray to remove the surface stained material. The water pressure selected for rust removal is important to preserve the existing paint and glass beads that are on the surface of the paint. Glass beads are used to reflect paint color to the pilots under low light conditions. The amount of water pressure used to remove rust build-up must be less than the pressure used to remove paint build-up. The higher pressures used to remove paint will also remove the glass beads from the paint. Pressure washers that have a pressure range from 1,000-3,500 pounds per square inch and water volume of 5-10 gallons per minute are recommended[8].

Chemical treatments remove the stains through chemical means. However, commercial rust remover (ex. CLR®, Rustlick) results in the chemical agent damaging the glass beads on the surface of the paint. This renders the markings ineffective during low light conditions[4]. The FAA Technical Center has had success with pressure washing with diluted bleach added to remove rust-colored stained areas[9]. The FAA P-620 specification does not discuss restoring the condition of existing markings.

The best practice is to remove stains prior to repainting. Applying paint over existing stains results in the stains re-appearing in a few months. When repainting, the best practice is to remove the majority of the stain and re-apply the paint markings using a modified water-borne paint that will resist staining[10].

When repainting under a project funded by the Airport Improvements Program (AIP), the construction specifications require the loose markings be removed[11].

[8] Speidel, Donna. "Airfield Marking Handbook." Reports and Products. Innovative Pavement Research Foundation. Sep. 2008. P. 36

[9] Cyrus, Holly. FAA. 2014. FAA Technical Center. Personal interview by Beran Black.

[10] Speidel, Donna. "Airfield Marking Handbook."P. 40.

[11] "Standards for Specifying Construction of Airports", P. 432.

Modification to the Paint Material Specification

The FAA specification for paint includes three types of paint: Types I, II and III. Type I and II are commonly used. Type I is intended for those locations where slower curing is not a problem. Type II is intended for locations where faster curing is desirable. Type III paint uses cross linking resin which will produce a thicker, more durable coating.

Waterborne paint is the most common paint used. The Federal specification for waterborne paint is TT-P-1952E. The FAA specification includes other paints including solvent-based, epoxy, and methacrylate. These non-waterborne paints are more expensive and therefore are generally not selected.

As previously noted, staining of paints occurs in numerous locations. Paint manufacturers are aware of the problem. Therefore, paint manufacturers have previously investigated measures to reduce paint staining. The manufacturers have successfully modified the Federal paint specification TT-P-1952E to make the paint less susceptible to staining by incorporation of rust-inhibitor additives to the paint[12]. A modified version of TT-P-1952E that resists staining has been used successfully and has kept the markings white for five to seven years. The modified paint has been used at Naval Air Station Patuxent River, MD and Manassas Regional Airport, VA[13]. All 3 types of paint (I, II and III) can be modified[14].

In addition to the incorporation of rust-inhibitor additives to the paint, the pigment content and fineness, is changed in the modified paint. The standard, non-modified TT-P-1952E specification paint has a pigment content of 60-62%. Standard specification paint contains a higher amount of calcium carbonate than the modified TT-P-1952E specification. Calcium carbonate absorbs the rust. This makes the standard TT-P-1952E paint susceptible to staining from rust-laden rain water sheet-flowing across and being absorbed by the paint[15]. In the modified paint, the pigment is lowered to around 40%. Additionally, the pigment is a finer, smaller particle size, in the modified specification, resulting in a less porous paint[16]. The lower percentage of pigment and finer pigment material reduces the absorption and staining of the paint.

When specifying TT-P-1952E Type III paint, the only latex paint currently available is the patented HD-21A[17]. The Dow Chemical Company makes the FASTRACK™ HD-21A high-build system. FASTRACK has over 10 years of track record on roadways and is specified by many state DOT's. The high-build system refers to the thickness of the applied paint. Standard paint is applied around 18-20 mils thick. The HD-21A is applied up to 30 mils thick which has proven to extend the life and reflectivity of the

[12] Villani, Dave – Ennis Flint. July 2015, Email correspondence to John Gorham.

[13] Speidel, Donna – Sightline AMC. August 2015, Email to John Gorham.

[14] Speidel, Michael – Sightline AMC. 2014, Personal interview by Beran Black.

[15] Fox, Chris - Sherwin Williams. 2014, Personal interview by Beran Black.

[16] Hudson, Betsy - Pavement Marking Solutions. 2014, Personal interview by Beran Black.

[17] Villani, Dave - Ennis-Flint. July 2015. Email correspondence to John Gorham.

paint[18]. The significance of the glass beads sized to the type of paint used is discussed later in this section.

The modified paint specification was originally designed to protect against top surface, sheet flow rust staining. The modified paint's ability to resist rust staining from the bottom up has not been determined[7]. However, the modified paint's properties, such as the lower pigment percentage, may help with both the top surface and bottom up staining[9]. A trial area of modified paint with known bottom up staining is recommended as an additional investigation in Section VIII of this report.

To further support the bottom up staining resistance, Sherwin Williams reports that a modified TT-P-1952E Type III paint with a rust inhibitor has been applied to steel test panels. Staining from the underlying steel has not been found. The rust inhibitor has a proven history as an additive and has been used in architectural products that are applied onto steel. Both algae and rust inhibitors have been successfully added to paint without creating issues with other paint properties[19].

The FAA requires a modification to standard be issued in order to use the modified TT-P-1952E specification[20]. The FAA has approved the use of the modified paint on previous projects to reduce staining[21].

Figure 12 was taken two years after Figure 11, demonstrating the advantage of using the best practice modified formulation of TT-P-1952E to resist the rust staining[22].

Figure 11 - Stained markings before modified paint (Speidel, 2008)

Figure 12 - Modified paint 2 years after (Speidel, 2008)

[18] "FASTRACK™ HD-21A High Durable Polymer", www.dow.com/fastrack. 2015.
[19] Fox, Chris -Sherwin Williams. 2014, Personal interview by Beran Black.
[20] Merck, John - FAA New England. 2014, Personal interview by Beran Black.
[21] Carneal, Chuck - Safety Coatings. 2014, Personal interview by Beran Black.
[22] Speidel, Donna. "Airfield Marking Handbook." P. 33.

The use of a modified TT-P-1952E paint has been successful at five airports[23]. A case study presented in the October 2013 "*Airport Improvements Magazine"* described the rust staining at the Naval Air Station Patuxent River, in St. Mary's County, Maryland as follows:

> *"It was really bad,"* recalls Airfield Manager Jim Fletcher. *"It was almost like somebody came out and sprayed tar over the top of the paint – it was that dark. You would never guess that the paint was white."*

The Naval Air Station's problem began after a routine painting in 2002, when crews used a product with different specifications because of new environmental and performance standards.

> *"After that, we started to see the discoloration in the white pigment,"* says Ken Barbour, AICUZ/RAICUZ Program Manager for the Naval District Washington. *"The rust color eventually overtook the light pigment. It was more of a brown stripe than a white stripe."*

New staining is isolated to cracks in the pavement that allow the iron to seep up to the surface and stain only around the cracks. Sightline Airport Marking Consultants counseled the Naval Air Station to continue using the modified specification waterborne paint for future marking projects.

> *"The fact that the majority of those markings are still white is a testimony to the formula modification,"* Donna Speidel, President, AMC explains.

Potential Alternative Methods

Potential methods were identified from interviews within the industry. The methods seek to reduce staining from the two previously discussed (see Section II) primary staining modes: 1) over-pavement sheet flow during rain events that carry rust onto the paint markings, and 2) rusting aggregates that create point stains within the pavement markings.

Factors to consider for each method include reflectivity of paint, bead size selection, thickness of the paint, pavement friction and abrasion resistance. Because the glass beads affect these factors, a discussion of the selection of the glass beads is provided as background prior to the discussion of the alternative methods.

Glass Beads

Glass beads are placed on the surface of paint to reflect the paint to pilots under low-light conditions (e.g., night, fog). Glass beads are placed immediately after the painting.

[23] Carneal, Chuck - Safety Coatings. 2014, Personal interview by Beran Black.

Light that is directed toward the bead is bent or refracted inside the bead. The greater the degree of bending, the more light will be returned to the light source[24].

Similar to paint, the FAA specifies three bead types: Type I, III and IV. Type II beads are no longer used. All three types are specified as Federal Specification TT-B-1325D, Gradation A. Type I beads are used when marking on a frequent basis; at least every six months. Type III beads are used when higher reflective value is desired[25].

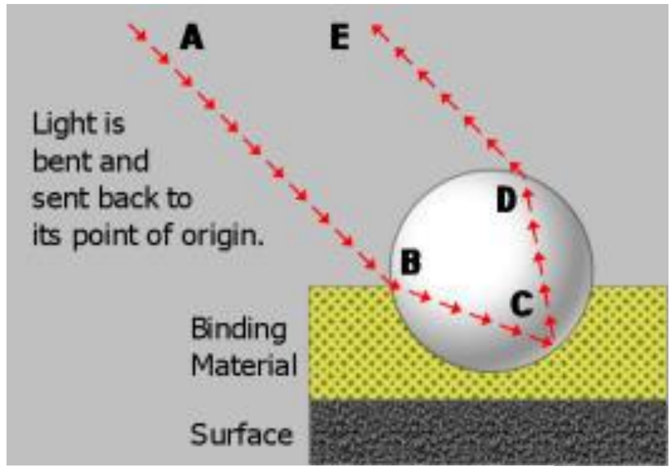

Figure 13 - How glass beads work (Speidel, 2014)

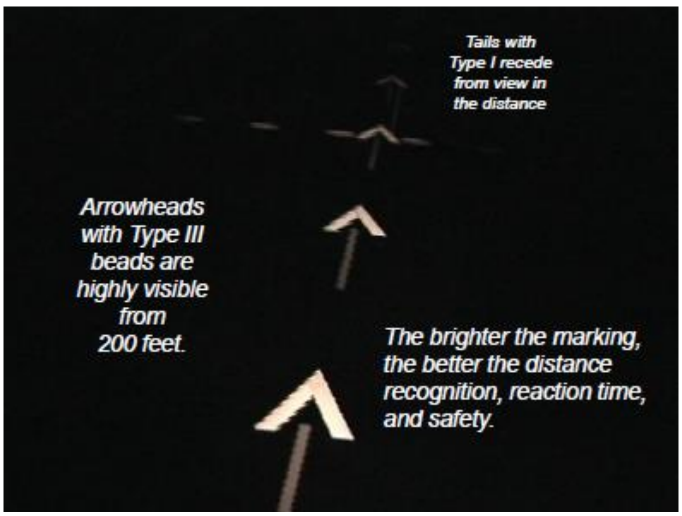

Figure 14 - Type I and III bead comparison (Speidel, 2014)

Each bead type is used with a specific paint type. FAA P-620 specification specifies for waterborne paint the bead-paint combinations as follows:

Paint Type	Glass Beads-Type I	Glass Beads-Type III	Glass Beads-Type IV
Waterborne Type I or II	Compatible	Compatible	Not Compatible
Waterborne Type III	Not Compatible	Compatible	Compatible

Table 2 – Bead Type and Paint Type Compatibility (reference FAA P-620 Specification)

[24] Speidel, Donna. "Runway and Taxiway Painting and Best Practices from the Airfield Marking Handbook". Webinar slides. May 2014.

[25] "Standards for Specifying Construction of Airports", P. 431.

The P-620 specification specifies bead types for solvent based, epoxy and methacrylate paint types as well. Because these paint types are not commonly used, they are not included in the table.

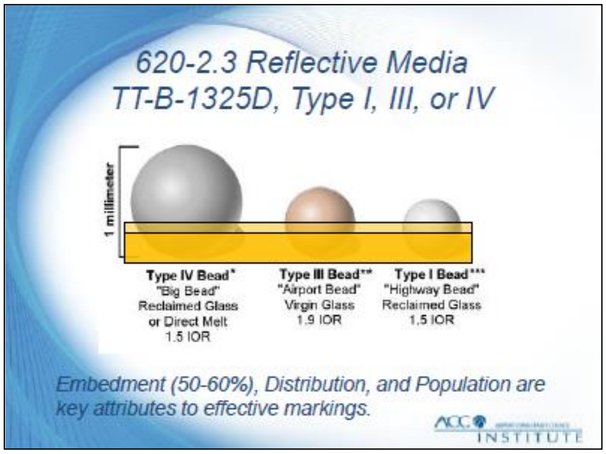

Figure 15 – Bead placement (Speidel 2014)

The FAA P-620 specification states that Type I beads shall be used when remarking on a frequent basis (at least every six months). From the Table 2, Type I beads are only compatible with Type I or II paint. Therefore, for airports painting longer than every 6 months a Type III or IV bead is required. Based on discussions with the industry, the Type III paint with Type III reflective beads (higher index of refraction) is the best combination[26].

The placement of the glass beads is important to the function of the beads, as well as the longevity of the beads. Bead placement is a function of the bead diameter and paint thickness. Beads are round and can be easily "knocked out" of the surface of the paint if not properly anchored in the paint.

A 50 to 60% bead diameter minimum anchor depth is recommended as shown in Figure 15. An example of a poor bead anchor, where the beads have little anchor depth, is shown in Figure 16[27].

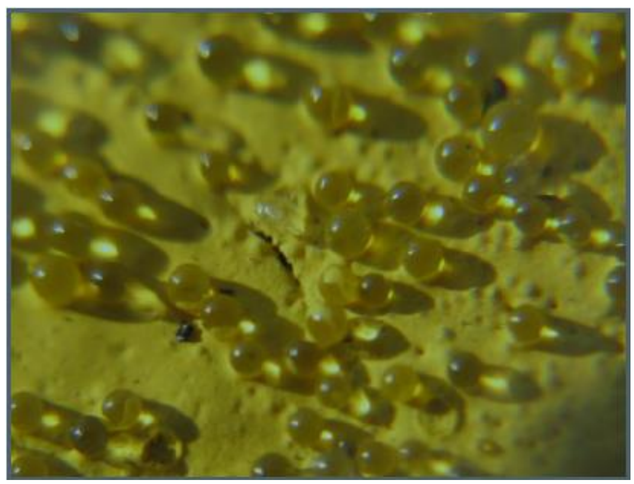

Figure 16 – Poorly placed beads (Speidel, 2014)

Type I, Type III and Type IV Gradation A beads have maximum diameters of 850, 1180 and 1700 microns, respectively. [28] The respective conversion to mils is 33, 46 and 66 mils[29]. Therefore, based upon the 50 to 60% anchor depth, the wet film paint thickness for Type I beads should be 17-20 mils; the wet film thickness of Type III beads should be 23-28 mils; and the wet film thickness for Type IV beads should be 33-40 mils.

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[26] Speidel, Michael - Sightline, LC, Airfield Marking Consultants; Hall, Kevin - Potters Industries. 2014, Personal interviews by Beran Black.

[27] Speidel, Michael - Sightline Airfield Marking Consultants. 2014, Personal interview by Beran Black.

[28] "Beads (Glass Spheres) Retro-Reflective", Federal Specification TT-B-1325D, August 6, 2007.

[29] 1 micron = 0.0393700787 mil, www.google.com, 2015.

The P-620 specification requires a test strip to ensure the rate of application is being achieved. A recommended modification to the P-620 specification would be to add a requirement to measure the mil thickness within test strip and full production areas to ensure the proper paint thickness and thus bead embedment is achieved. The specification should include a thickness for each paint and bead type used. Steel plates could be specified to be statistically placed in random locations within the areas to be painted in order to determine an average thickness of the paint as compared to the specified thickness. An example of a thickness measurement and tool is shown in Figure 17.

Figure 17 – Paint thickness measurements and Mil Thickness measuring tool -lower right (Speidel 2014)

It is noted that the FAA P-620 specification does not specify the thickness of the paint to support the bead embedment requirements. The P-620 specification provides a maximum square footage of paint for each gallon. This implies a thickness if the paint is applied at a uniform rate. For instance, the 115 square feet per gallon specified for Type I paint in the P-620 specification calculates to 14 mils. To adhere the Type I beads at 60% bead diameter embedment, a 20 mil paint thickness is required. To achieve a 20 mil thickness, the paint should be applied at 81 square feet per gallon. This is a significant difference than the 115 square feet per gallon specified. The P-620 specified application rates should be evaluated to result in the required thicknesses. The calculations are shown in Table 3.

P-620 Specification				Recommendation	
Paint Type	Bead Type	Application Rate SF/gal. Max.	Resulting Thickness* Wet mils	Application Rate** SF/gal Max.	Required Thickness*** Wet mils
Waterborne Type I or II	Type IA	115	14	81	20
Waterborne Type I or II	Type IIIA	115	14	56	29
Waterborne Type III	Type IIIA	90	18	56	29
Waterborne Type III	Type IVA	55	29	40	40
* Mil thickness calculation: Invert 7.48 Gallon/CF = 0.134 CF/gallon. Mil thickness = 0.134 CF/gallon x 1728 Cu. Inches/CF x 1 SF/144 Sq. Inches x gal./SF rate. Example for Type I/II paint = 0.134 x 1728 x 1/144 x 1/115 = 0.014 inches (14 mils) ** Recommended paint application rate to achieve required Mil thickness. *** Required Mil thickness to achieve 60% bead diameter embedment. References: FAA Advisory Circular 150/5370-10G P-620 specification and Federal Specification TT-B-1325D “Beads (Glass Spheres) Retroflective”					

Table 3 – Paint Application Rates When Beads Applied (Specified vs. Recommended)

The Sherwin Williams and Franklin Paint Type I/II data sheets were consulted for the manufacturer’s recommended mil thickness. Both companies report coverage at 15 wet mils. This meets or exceeds the current FAA specification P-620 thickness of 14 mils for Type I/II paint. However, the thickness is less than needed to properly anchor glass beads as shown in Table 3.

Clear Coat over the Paint

A concept for reducing sheet flow staining is to provide clear coat over the top of the paint. This would be similar to a homeowner applying a water sealant over stained wood to protect the wood from the weather. Factors to consider in providing a clear coat include skid resistance, abrasion of the coating and deterioration of the bead reflectivity. US Specialty Coatings indicated that a surface clear coat application for the protection of paint would have to be developed. The manufacturer would be concerned with the loss of bead/paint reflectivity and skid resistance[30].

Providing a clear sealant over the top of the paint would help with preventing surface staining, by providing a non-porous and non-absorbent surface (paint is both porous

[30] Irani, Herman- US Specialty Coatings. Personal interview by Beran Black. 2014.

and absorbent). This would allow the rust to be washed off, either by natural storm water or pressure washer.

Sightline AMC tried using a sealant (glass coating 1 mil thick) to seal markings. The markings were easier to clean and resisted fading, however, the reflectivity of the beads was reduced by 50%[31]. Reduced reflectivity impairs the paint's function. The FAA technical center used a clear siloxane surface sealer product made by ADSIL to seal markings. The reflectivity was reduced 40%[32]. ADSIL products are designed for anti-graffiti applications, as well as sealing concrete, hard tile, terrazzo and tile floors[33]. The product is not designed to seal pavement paint or bituminous pavement.

To overcome the reduced bead reflectivity issue after clear coating, the higher reflectivity Type III or IV beads could be used instead of the Type I beads. For example, from the FAA P-620 specification, Type III beads require an initial reading of at least 600 mcd/m²/lux on white markings and at least 300 mcd/m²/lux on yellow markings. Considering a clear coat reduction of 50%, this would result in 300 (white) and 150 (yellow) mcd/m²/lux values. Assuming Type I bead reflectance is the lowest acceptable standard, the Type III 50% reduced values are close to the Type I standard. Refer to Table 4 – Bead Reflectance Comparison for these values. This analysis indicates there is a possibility to overcome the reduced glass bead reflectivity values when clear coating.

Bead Type Gradation A	Reflectance on White mcd/m²/lux	Reflectance on Yellow Markings mcd/m²/lux
Type I	300	175
Type III	600	300
Clear Coat over Type III (50% reduced Reflectance)	300 (Equal Type I)	150 (15% of Type I)

Table 4 – Bead Reflectance Comparison (Reference FAA P-620 Specification)

The loss of friction by clear coating pavement markings and beads would have to be investigated. ADSIL reports that their products provide foot traffic slip resistance. Pavement skid resistance would have to be investigated and evaluated. Additionally, the friction created by aircraft braking (high heat and friction) would have to be considered when evaluating the clear coating material properties. The larger Type III and IV beads would increase the surface texture and therefore offset the loss of friction created by the clear coating.

[31] Speidel, Michael - Sightline Airfield Marking Consultants. Personal interview by Beran Black. 2014.

[32] Cyrus, Holly. -FAA Technical Center. Personal interview by Beran Black. 2014.

[33] "Microguard." ADSIL Microguard. 2014. <http://mymicroguard.com>.

Pavement Pretreatment Prior to Painting

The goal of pretreatment is to prevent the second form of staining: rust point paint staining. The concept is to create a barrier between the rusting aggregate and the paint. This is likened to a homeowner priming wood before painting. A factor to consider with this alternative is that pavement paint is typically applied without a primer or pre-sealant. The placement of the primer and sealer is an additional step in the painting process which will delay the opening of pavements. This technique would be new to the industry. The two methodologies, pavement primer and pre-sealant are discussed below.

Pavement Primer

Similar to painting a building, applying a primer prior to the paint may remove the bottom up rust from occurring by reducing moisture and oxygen which creates the rust. Water repellent, solvent-based paints appear to work the best in these applications. Because waterborne paints are porous, they allow the migration of water to the aggregate, resulting in staining. Solvent-based paints have been replaced by water borne paints in recent years, due to stricter environmental requirements. Solvent-based paints emit harmful volatile organic compounds (VOCs), thus precipitating the environmental requirements. Solvent based paints are more costly than waterborne paints. Advances in paint technology have resulted in high quality water-based paints that are in many respects equal to, or superior to their solvent-based equivalents[34].

The application of water borne paint over solvent-based paint may result in peeling. An acceptable application method for applying water borne paint over solvent-based paint would need to be developed[35]. This would be similar to oil-based primer and a latex top coat used in building applications.

The application of a primer coat prior to painting could follow the same procedure as the application of temporary paint in the FAA P-620 specification. The primer would be placed at 7 mils thickness. After drying, an additional 15 mil final coat with glass beads would be painted[36].

Pavement Pre-sealant

Pre-sealants were considered to prevent both methods of staining: sheet flow and point staining.

[34] "Water based vs Solvent based," Paint Quality Institute, 2015, http://www.paintquality.com/en/understanding-paint/water-based-vs-solvent-based.

[35] Irani, Herman - US Specialty Coatings. Personal interview with Beran Black. 2014.

[36] Hudson, Betsy - Pavement Marking Solutions. Personal interview with Beran Black. 2014.

The use of gloss sealants to encapsulate the pavement was considered. However, gloss sealants are not manufactured for bituminous pavements. The problem with gloss sealants is that they produce an impenetrable surface, which makes bonding to other coatings, such as paint, an issue[37]. Additionally, a gloss surface creates a slippery surface.

Sealing pavements is a common method to preserve the pavement life. Sealing the pavement would encapsulate and therefore repel the moisture from contacting the aggregates that contain iron. This would eliminate the development of the rust point stains. In the pavement cores taken from the NH airports, those that were sealed exhibited no surface rusting.

Figure 18 - Sealed and painted pavement

Pavement sealants can be painted. The pavement would be coated with a sealant measured to within a 6-inch width either side of the marking – similar to the black border requirement in FAA Advisory Circular 150/5340-1, "*Standards for Airport Markings*". For example, for a 6-inch paint stripe, an 18-inch wide pre-sealant would be placed centered on the stripe. The 6-inch paint stripe would be placed over the 18-inch wide sealant.

Typically, sealants are applied via an 8-foot-wide or larger spreader bar on the back of a spreader truck. To seal a narrower area, such as 6-inches either side of the markings, modifications to the typical spreader bar method of sealing would be required.

Adequate cure time of sealants and temperature is required to prevent paint-to-sealant bonding issues[38]. A typical cure time is 30 days. The cure time and temperature needs to be considered in the project phasing.

Where significant staining occurs from rainwater sheet flow, a complete pavement surface sealant could be applied to prevent the rusting of the surface aggregates. Minnesota DOT uses water borne paints and noted they have iron in their aggregates. The Minnesota DOT has reported that they have had success by sealing their airport pavements to mitigate the issue[39]. An additional benefit of sealing pavement is extending the pavement life.

FAA Advisory Circular 150/5370-10G includes five different specifications for pavement sealants; P-608 Emulsified Asphalt Sealant, P-626 Emulsified Asphalt Slurry Seal

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[37] Carneal, Chuck - Safety Coatings. Personal interview with Beran Black. 2014.

[38] Cyrus, Holly - FAA Technical Center. Personal interview with Beran Black. 2014.

[39] Shroeder, John – Minnesota DOT. Personal interview with Beran Black. 2014.

Surface Treatment and P-629, P-630, P-631 which are various Coal Tar Emulsion Surface Treatments. The type used varies based on the airport area, such as a runway or taxiway, and aircraft weight criteria. Coal-tar-based sealcoat is a potent source of polycyclic aromatic hydrocarbons (PAHs) to air, soils, streams and lakes, and homes[40]. The environmental impacts of asphalt sealants should be considered.

A trial of various sealants should be considered to test their resistance to rust staining. It was noted at one NH airport with raveling, or surface aggregate loss issues, the sealed areas did not have the aggregate loss issues experienced elsewhere on the airport.

A San Francisco airport solved a rusting aggregate problem by surface sealing. Test results showed that the airport had high Pyrite content in the aggregate. This created thumb-sized rust spots on the runway. The remedy was to place a single coat of Star® Rust Arrest. Rust Arrest is a specialty coating used for asphalt surfaces exhibiting rust spots and streaks[41]. After application of the Rust Arrest, two coats of Star Aviator® a rubberized, refined, tar emulsion were applied. The application was anticipated to be repeated every four years. The treatment was 36 mils in thickness[42].

Alternative Pavement Marking Types

Non-waterborne paints provided in FAA Specification P-620 include epoxy, methacrylate, solvent-based and thermoplastic. Non-waterborne paints repel moisture. This would prevent water from coming into contact with oxidizing of the iron in the aggregates. In turn this would reduce the development of rust. Typically, the non-waterborne materials cost is 5 -10 times higher than waterborne paint. Because of this higher cost, the non-waterborne paints are not commonly used. Additionally, thermoplastics are not allowed for use on runways[43].

Grooving

FAA Specification P-621, *Saw-Cut Grooves* may also be a consideration for mitigating the rust stained markings. The specification includes a ¼-inch-wide by ¼-inch- deep groove, cut transverse to the aircraft travel direction.

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[40] "You're Standing on It! Health Risks of Coal-Tar Pavement Sealcoat", USGS, 2015, www.usgs.gov

[41] "Rust Arrest", *Starseal Specialty Technology and Research*, 2014, http://starseal.com.

[42] Ganger, Bill -Star Seal. Personal interview with Beran Black. 2014.

[43] Cyrus, Holly - FAA Technical Center. Personal interview with Beran Black. 2014.

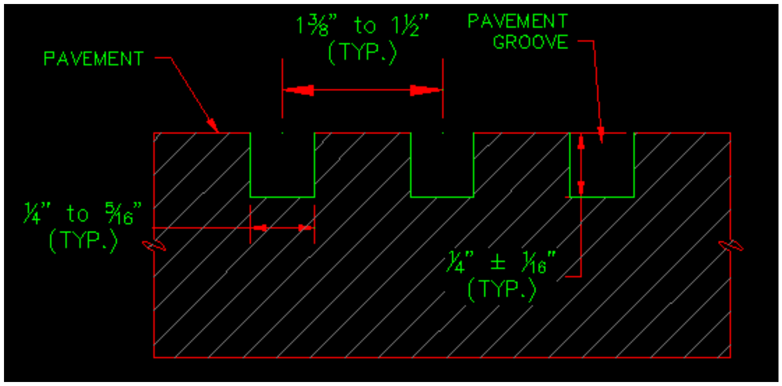

Figure 19 - Grooving detail

The grooves would concentrate the rainwater flow. This would increase the velocity of the water and, in theory, allow the rust deposits to stay suspended in the water until the water runs off onto the pavement shoulder. On non-grooved pavement, rainwater spreads out and travels slower. Slower water drops the rust particles onto the pavement and paint surface. The grooves could be cut for the larger markings (aiming points, touch down zone, threshold and edge stripes). Figure 20 shows reduced rust stains where the pavement is grooved (black arrow pointing to grooved pavement).

Figure 20 – Grooved Pavement Example (white with black arrow) and not grooved (stained) pavement (Speidel 2008)

A downside to the grooving is that the saw cuts in the pavement will expose the aggregate within the walls of the groove. This could result in additional rust staining. However, any run-off staining would be below the pavement surface.

VI. LIFE CYCLE COSTS ANALYSES

20-year life cycle costs were calculated for four alternative paint types. The calculations use a present value analysis. Present value reduces the initial installation and the future costs of maintenance and replacement into present day costs. The analysis looks at a 20-year time frame. The type of paint and beads used affects the paint maintenance and replacement frequency. By looking at the 20-year cycle, alternatives can be compared.

The estimated values provided below are for comparison purposes. The actual costs would be site specific when factors such as the quantity of markings and project phasing are considered. The analyses found the following:

- Type I/II paint with Type I beads: $32.29/SF (20 year costs)

  This is the most common method of painting. A 2014 FAA update to the P-620 paint specification allows the use of Type I beads if the painting frequency is less than every 6 months. Historically, airports have been painting longer than every 6 months. For example, commercial service airports tend to paint every year for the annual FAA inspection. Therefore re-painting every year was considered. Paint removal was considered after every other painting.

- Modified Type I/II paint with Type I beads: $32.66/SF (20 year costs)

  This alternative modifies the Type I/II paint to resist staining. Painting and removal assumptions are the same as the Type I/II paint with Type I beads described above.

- Type III paint with Type III beads: $17.05/SF (20 year costs)

  This alternative utilizes the cross linked resin Type III paint with the Type III beads. The paint is thicker and more durable. The Type III beads are larger and more reflective than the Type I beads. The painting frequency is assumed to be every two years because the paint is thicker. The thicker paint is assumed to resist the rust point staining for these two years. The sheet flow staining would still be a consideration even with the thicker paint. Every other painting event, except the initial painting, includes marking removal costs per the P-620 specification.

- Modified Type III paint with Type III beads: $10.15/SF (20 year costs)

  This alternative modifies the Type III paint to resist staining. The painting frequency is increased to every four years[44]. Every other painting event, except the initial painting, includes marking removal costs. Washing of the paint is

[44] Carneal, Chuck - Safety Coatings. Personal interview with John Hehir – Jacobs Engineering. 2014.

assumed to accumulate between the painting events. A mid-cycle washing event was considered every two years.

Based upon the above analysis, the Modified Type III paint with Type III beads provides a cost advantage over other alternatives estimated. Life cycle costs and related assumptions used in the analyses are provided in Appendix H.

Besides the quantified life cycle costs presented, other qualitative factors may need to be considered when selecting the preferred treatment such as those associated with airport user safety.

VII. CONCLUSIONS

Laboratory sieve analyses were conducted on a total of eleven pavement cores. At least one core from each of the five airports was analyzed. The analysis indicates the aggregates are uniform in gradation and generally conform to the current FAA specifications.

A laboratory "magnet test" was conducted to determine the amount of ferrous materials in the portion of the pavement core material passing the No. 4 sieve. The percentages ranged from 0.5 to 13.4%. Quarries in New Hampshire's western and northern areas, as well as one quarry in Maine's western boundary, had the highest ferrous content. Quarries in the middle to the southern part of New Hampshire had lower ferrous contents.

Scanning Electron Microscope (SEM) and Energy Dispersive X-Ray Spectroscopy technique (EDS) techniques were used to analyze stained paint chips. High levels of iron were detected in stained locations confirming that rusting of iron is the cause of staining.

The petrographic analyses identified primarily metamorphic and igneous materials containing ferrous compounds.

A laboratory accelerated oxidization test was conducted on a pavement core from Claremont to simulate weathering of the aggregates. Rust formed on the surface of the pavement core. This test could be used to 'pilot' test alternatives in the laboratory prior to the field testing.

Submittal data was provided for each of the five airports included in the study. Pavement and paint construction submittal data for fourteen projects were reviewed. The data provided pavement data from four plants and eight quarries. Paint data for three of the fourteen projects was made available. The data indicates the most commonly used paint was Type I/II waterborne paint.

Modification to the FAA P-620 paint specification has successfully mitigated the rust staining in other areas of the country. Water blasting to remove the rust deposits from the paint surface has also been successful. Alternative approaches, such as clear coating the paint, pretreating the pavement below the paint with either a solvent primer or sealcoat, or grooving the pavements are potential alternatives.

The 20-year life cycle cost analyses indicate that the Modified Type III paint with Type III beads is the least cost alternative. The cost analyses consider the recent (2014) FAA P-620 specification's painting frequency and paint removal requirements.

VIII. RECOMMENDATIONS FOR ADDITIONAL INVESTIGATIONS

Based upon the information gathered from the study, the recommendations for additional investigations to consider are described below.

Recommendation #1 - Testing of Alternatives

The industry has identified methods to reduce staining of paint. This recommendation considers testing the alternatives to confirm the identified methods performance. The methods to consider are as follows:

- Modified Type I/II with Type I beads, modified Type III with Type III beads and standard Type III paint with Type III beads has not been readily used and therefore does not have an extensive performance record. Utilize these paints and conduct comparisons of their performance. Apply to pavements with known sheet flow and bottom-up rust staining. Document performance by photographic comparison, reflectivity and thickness measurements every six months for the life of the paint.
- Apply standard Type I/II or III paint to areas that receive an asphalt seal coat. Document performance by photographic comparison and reflectivity every six months for the life of the paint alternatives.
- Groove paint markings (modified and standard Type I/II or Type III paints) in areas of known staining. Continue grooves to the edge of the pavement to outlet the rust-laden rain water off the pavement. Document performance by photographic comparison and reflectivity every six months for the life of the paint alternatives.

For each of the above alternatives, prepare a control sample. Consider painting a one square foot control sample on metal plate during the paint application. Store the control sample in a weather proof area (ex. office or hangar). Include the control sample in the photographs for comparison purposes.

Recommendation #2 - Identify Staining and Non-staining Aggregate Sources

The prevalence of iron bearing materials in the aggregate sources studied may make removal of the iron bearing materials difficult for the material suppliers. Materials would have to be imported from a distance increasing the costs of the projects because of the added hauling costs. Therefore, this recommendation would be to identify sources of aggregates that have the potential for staining. The recommendations are as follows:

- FAA specifications P-401/P-403 includes a 'lime slurry' test to identify aggregates that will cause staining. Aggregates are immersed in lime slurry. Based on the color change the potential for staining can be documented. Reference Section V of this report for the testing details. Test various sources of aggregate and document the results. The suppliers may be able to stockpile materials that pass the lime slurry test for use in future projects.

- Collect data on the staining severity and source of existing pavements. This would identify current and past sources that have the potential for staining. Complete this recommendation by performing visual staining severity surveys on pavements where the age and source (i.e. quarries) of the aggregates are known. Include projects that consider a representation of available NH sources. Identify the severity of point staining similar to a Pavement Condition Index survey method to measure raveling of pavement. Similar to raveling, randomly select areas within a pavement section and count point stains within a fixed area. The number of stains within the fixed area would be the indicator of the severity. Sheet flow staining would be measured based on the percentage of stained paint. Measure the area of stained paint and divide by the total area of paint. Data on the source of aggregate would be made available from construction submittal data. It is noted that the material composition within a quarry is subject to change with time as new material strata and veins of materials are exposed and mined.

- Investigate the availability of aggregate sources that are high in Felsic minerals such as Quartz and Feldspar while minimizing aggregates containing iron and sulfur.

<u>Recommendation #3 - Modify the FAA P-620 Specification</u>

Modify the FAA P-620 *Runway and Taxiway Marking* specification to include thickness measurements and the alternative to utilize a modified version of TT-P-1952E that resists staining.

- The thickness of the paint controls the durability and life of the paint. A thicker paint lasts longer and therefore extends the service life. Glass beads readily achieve the required embedment depth in thicker paint. Conversely, beads sink too deeply into paint that is too thick, reducing reflectivity and can damage pavement.

  The current FAA P-620 specification requires an application rate in a maximum area per gallon (e.g. 115 ft^2/ gallon maximum). The specified rate, in theory, equates to a thickness of paint. Consider modifying the FAA P-620 paint application rates to ensure the paint wet mil thickness required to properly anchor the glass beads is achieved.

With respect to quality control during construction, typically contractors do not pre-calculate the area of paint markings against the number of gallons in their applicators. This makes quality assurance thickness measurements of the paint difficult to ensure. Direct measurements of thicknesses of the paint would provide more consistent paint thicknesses. Paint thickness would be specified based on the type of paint (e.g. Type III paint 24-29 mils) in lieu of the current P-620 application rate.

Paint thickness testing would consist of placing a metal control plate randomly within the test strip and production areas. The steel plate would provide a smooth surface from which to conduct the thickness measurements. Accept or reject the painting based on a thickness range specified in the FAA P-620 specification.

- The FAA P-620 specification would include the option to specify a modified version of TT-P-1952E that resists staining. The modified paint has proven to be resistant to rust staining. The quantitative cost analyses indicate the modified Type III paint with Type III beads provides the lowest life cycle costs.
- Add a requirement to the FAA P-620 specification to submit, in addition to the paint material, the equipment, personnel qualifications, dates, pavement life and weather conditions during the installation such as temperature, humidity, wind speed and amount of sunlight. This additional record keeping will provide a more complete history of the paint construction.

GLOSSARY OF TERMS

Aggregate- a material or structure formed from a loosely compacted mass of fragments or particles

ASTM- American Society for Testing and Materials

Bituminous (Concrete) Pavement- A concrete made with bituminous material as a binder for sand and gravel

Candella- the SI unit of luminous intensity

CF – cubic feet

Cu. Inch – Cubic inch

Epoxy- an adhesive, plastic, paint, or other material made from a class of synthetic thermosetting polymers containing epoxide groups.

Extraction- (ASTM D2172 *Standard Test Methods for Quantitative Extraction of Bitumen From Bituminous Paving Mixtures*). The test provides for the quantitative determination of bitumen in hot-mixed paving mixtures and pavement samples for specification acceptance, service evaluation, control, and research.

FAA Technical Center– Federal Aviation Administration's William J. Hughes Technical Center – Atlantic City, NJ

Ferrous– Containing or consisting of iron

Gal - gallon

Glass Bead– A small piece of rounded glass placed on the paint after painting. Beads come in various sizes.

Gradation– A series of successive soil particle sizes

Life Cycle Cost - Sum of all recurring and one-time (non-recurring) costs over the full life span or a specified period of a good, service, structure, or system.

Matrix- a surrounding medium or structure

mcd/m²/lux– milli-candella per one lumen per square meter

Methacrylate- an acrylic resin or plastic

Micrometer– One millionth of a meter

Millimeter– One thousandth of a meter

Mils- thousandths of an inch

Oxidation- the process or result of oxidizing or being oxidized

Petrographic- the branch of petrology dealing with the description and classification of rocks, especially by microscopic examination

Pigment- color (something) with or as if with pigment

Resin- a sticky flammable organic substance, insoluble in water, exuded by some trees and other plants (notably fir and pine).

Sieve- a utensil consisting of a wire or plastic mesh held in a frame, used for separating coarser from finer particles.

SF – square feet

Solvent- able to dissolve other substances

Thermoplastic- denoting substances (especially synthetic resins) that become plastic on heating and harden on cooling and are able to repeat these processes

Volatile organic compounds- compounds having high vapor pressures, low-to-medium water solubilities, and low molecular weights.

Water-borne- conveyed by, traveling on, or involving travel or transportation on water

X-rays- an electromagnetic wave of high energy and very short wavelength, which is able to pass through many materials opaque to light

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Appendix A

Airports Selected for Study – Screening Criteria

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NH Airport	Pavement Staining	Construction Data Available	Notes	Airport Selected
Colebrook	No	No	Not paved	No
Errol	Yes	Yes	Helicopter pad staining, small pavement area	No
Whitefield	Yes	Yes	Signficant staining; same source as Berlin	Yes
Berlin	Yes	Yes	Staining not as bad as Whitefield; paved approximately 1 year before/after Whitefield; use Whitefield as representative site	No
Gorham	No	No	Not paved	No
Twin Mtn	Yes	No	No construction data	No
Franconia	No	No	Not paved	No
Dean Memorial	Not sure	No	No construction data	No
Plymouth	No	No	Not paved	No
Newfound	Yes	No	No construction data	No
Lebanon	Not sure	Yes	Not sure of existing rust staining	No
Parlin	Yes	Yes	Airport manager does not want pavement cored	No

NH Airport	Pavement Staining	Construction Data Available	Notes	Airport Selected
Claremont	Not sure	Yes	Construction data available from Stantec	Yes
Hawthorne	Not sure	No	No construction data	No
Keene	Not sure	Yes	Construction data available from Stantec	Yes
Jaffrey	Not sure	No	No construction data	No
Nashua	Not sure	Yes	New runway	No
Manchester	Not sure	Yes	Painted frequently	No
Hampton	No	No	Not paved	No
Pease	Not sure	Yes	Taxiway concrete; Runway paved in 2 parts - data is older	No
Skyhaven	Not sure	Yes	Taxiway 2007. Pike Farmington pit may not be active any more	No
Concord	Not sure	Yes	Example of no staining on RW 12-30	Yes
Laconia	Yes	Yes	Example of staining	Yes
Moltonborough	Not sure	No	No construction data	No

Notes: The above data was recorded from project meeting with NHDOT on November 29, 2012.

Appendix B

Core and Paint Chip Locations and Photographs


PAINT PAVEMENT STUDY
KEENE-DILLANT HOPKINS AIRPORT
PAINT CHIP 1
CORE 1
CORE 2
PAINT CHIP 2
20
CORE 3
CORE 5
CORE 4
CORE 7
CORE 6

Photo 1 – Close up of paint sample 1. Note only the paint was removed.

Photo 2 – Proposed core locations 1 and 2. Located on the south central edge of the terminal ramp.

Photo 3 - Keene - Dillant-Hopkins Airport (EEN) Core 1

Photo 4 - Keene - Dillant-Hopkins Airport (EEN) Core 2

Photo 5 - Keene - Dillant-Hopkins Airport (EEN) Core 3

Photo 6 - Keene - Dillant-Hopkins Airport (EEN) Core 4

Photo 7 - Keene - Dillant-Hopkins Airport (EEN) Core 5

Photo 8 - Keene - Dillant-Hopkins Airport (EEN) Core 6

Photo 9 - Keene - Dillant-Hopkins Airport (EEN) Core 7


PAVEMENT PAINT STUDY
CLAREMONT MUNICIPAL AIRPORT
PAINT CHIPS 2,3,4,5
PAINT CHIP 6
PAINT CHIP 1
CORE 1
CORE 2
TAXIWAY C (WEST)
CORE 5
CORE 4
CORE 3
TAXIWAY C (EAST)
PAINT CHIPS 7,8,9

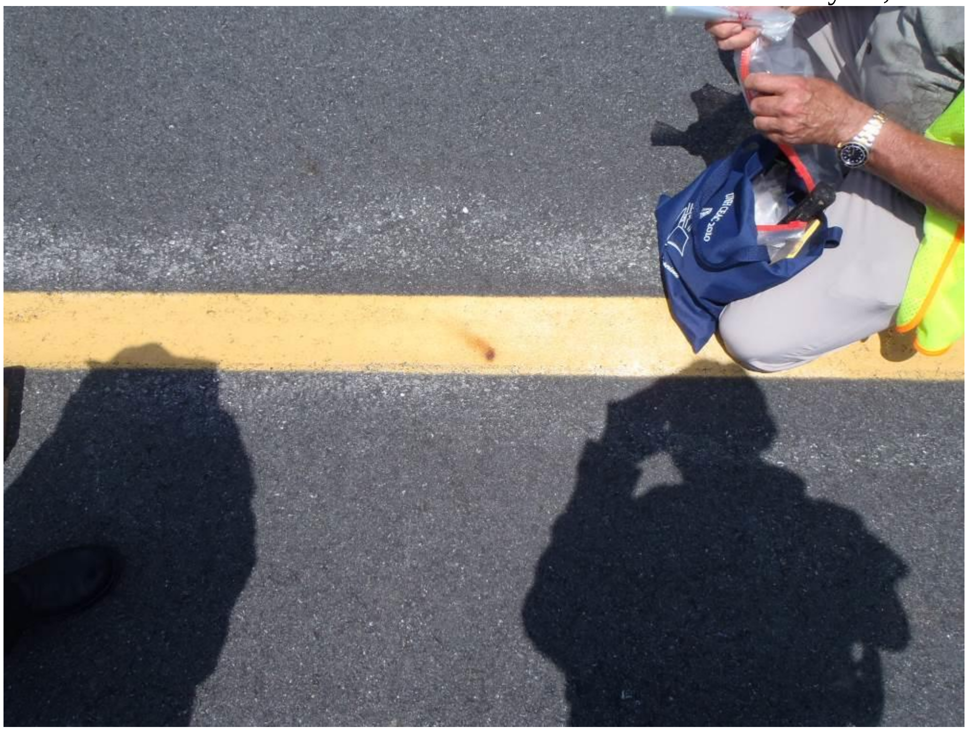

Photo 1 – Paint sample 1 taxiway C west about 200 feet west of taxiway A and C intersection.

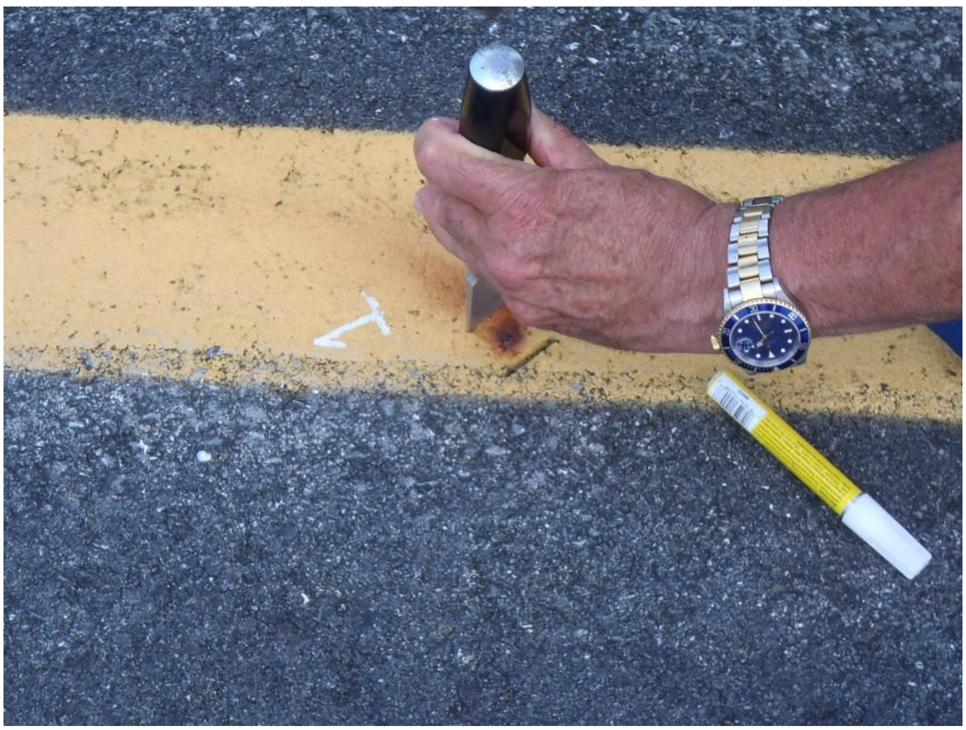

Photo 2 – Paint sample 1 being cut out.

Photo 3 – Paint sample 1 after being removed.

Photo 4 – Close up of core location 1.

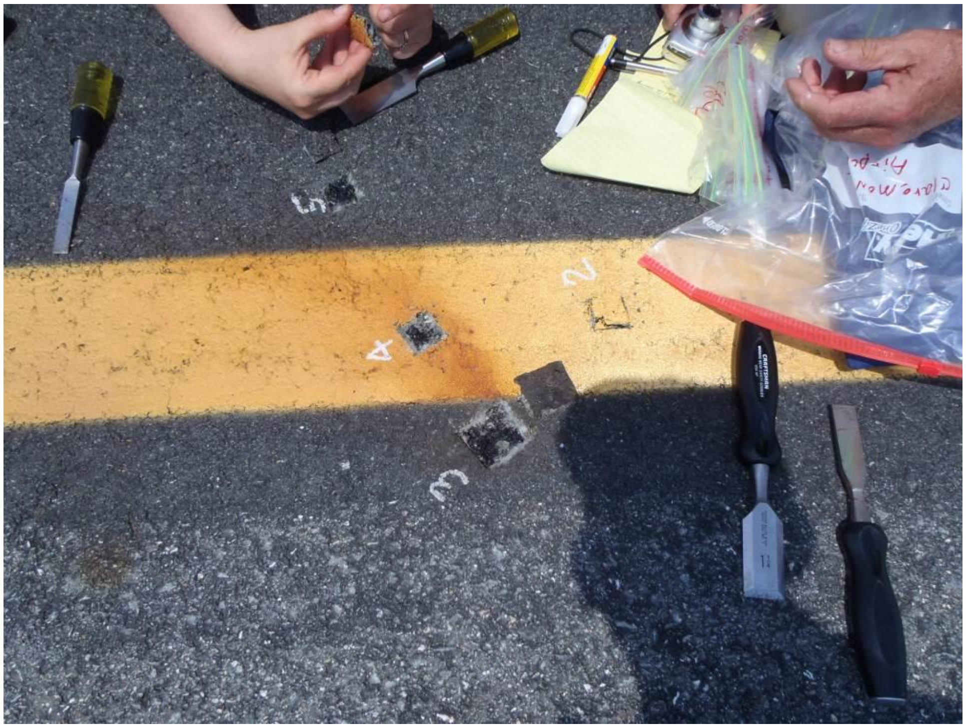

Photo 5 – Paint sample 2 located on no stained paint. Paint sample locations 3, 4 and 5. Sample 3 up gradient, 4 on the paint and 5 down gradient.

Photo 6 - Close up of proposed core location 2.

Photo 7 – Paint sample locations 7 and 8 west of core location 2.

Photo 8 – Paint sample locations 8 and 9. Note sample 8 is on a stain and 9 is not.

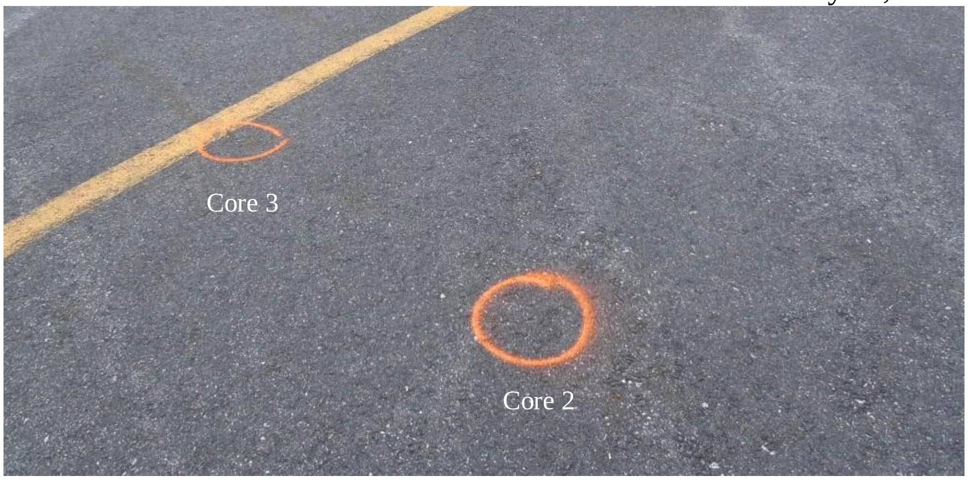

Photo 9 – Proposed core locations 2 and 3

Photo 10 – Claremont Municipal Airport (CNH) Core 1 – east end of taxiway C (west)

Photo 11 – CNH Core 2 – east of taxiway C (west)

Photo 12 – CNH Core 3 - west end of taxiway C (east)

Photo 13 – CNH Core 4 - west end of taxiway C (east)

Photo 14 – CNH Core 5 – Hangar Pavement in project AIP 3-33-0002-16-2005 pavement area


PAINT PAVEMENT STUDY
WHITEFIELD - MT. WASHINGTON REGIONAL AIRPORT
CORE 3
CORE 4
PAINT CHIPS 6,7,8,9,10
PAINT CHIPS 1,2,3
CORE 1
CORE 2
PAINT CHIPS 4,5

Photo 1–Proposed core location 1. Locations west of taxiway intersection.

Photo 2 – Close up of paint sample location 1 before sampling.

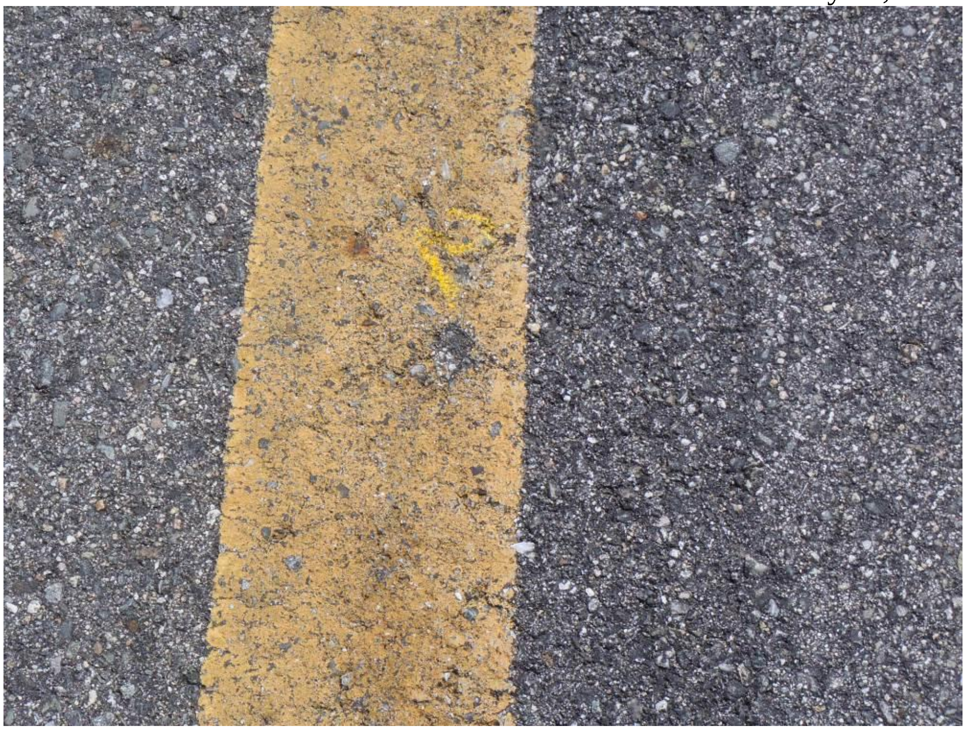

Photo 3 – Close up of paint sample location 2 before sampling.

Photo 4 – Sampling of rust stain location 3.

Photo 5 – Proposed core location Western end of taxiway at Hold Line

Photo 6 – Paint sample locations 4 & 5 western end of taxiway Hold Line

Photo 7 – Aiming point marking south side runway 10. Proposed core location 3

Photo 8 - Aiming point marking south side runway 10 paint sample location 6

Photo 9 – Paint sample 8 located west of proposed core 3.

Photo 10 - Aiming point marking north side runway 10 proposed core location 4

Photo 11 – Close up of proposed core 4.

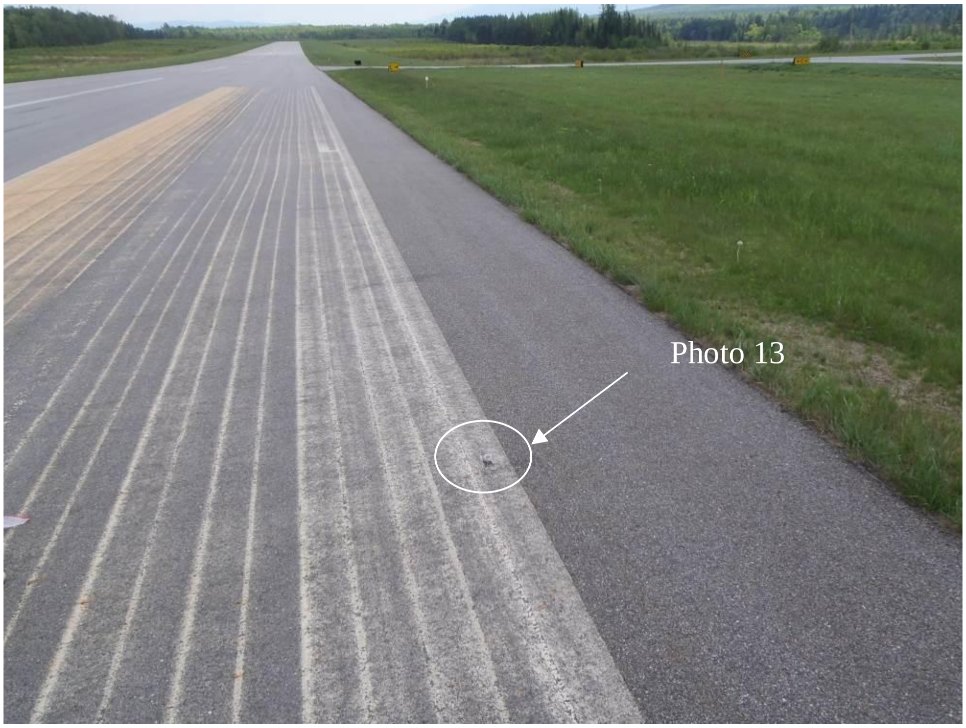

Photo 12 – Paint sample 10

Photo 13 – Close up of paint sample 10 after sample taken.

Photo 14 - Mount Washington Regional Airport (HIE) Core 1 from centerline of taxiway A near intersection with taxiway B

Photo 15 - HIE Core 2 from hold short marking taxiway A at runway 10 right side

Photo 16 - HIE Core 3 from tough down marking runway 10 end left side.

Photo 17 HIE Core 4 from touch down marking runway 10 end right side.

PAINT PAVEMENT STUDY

LACONIA MUNICIPAL AIRPORT

Photo 1 – Close up of sample 1 after sample was removed.

Photo 2 – Close up of sample 2 after sample was removed

Photo 3 – Close up of sample 3 before removal.

Photo 4 – Samples 4, 5 and 6 in threshold bar Runway 8

Photo 5 – Close up of paint sample locations 4, 5 and 6

Photo 6 – Southern most runway end light Runway 8. Paint sample 7 taken at base of light.

Photo 7 – Close up of paint sample 7 taken on the concrete light bar at the end of Runway 8.

Photo 8 – Close up view of paint sample 8 taken near the centerline of the threshold bar on Runway 8.

Photo 9 – Close up of paint sample 9 before removal.

Photo 10 – Paint sample 10 after removal.

Photo 11 Laconia Airport (LCI) Core 1 - blast pad left side runway 8 end

Photo 12 LCI Core 2 - blast pad right side runway 8

Photo 13 LCI Core 3 - taxiway C western end right side of ILS marking

Photo 14 LCI Core 4 - taxiway C centerline across from terminal apron


PAINT PAVEMENT STUDY
CONCORD MUNICIPAL AIRPORT
CORE 1
CORE 2
PAINT CHIPS 1,2

Photo 1 – Close up of paint sample.

Photo 2 – Coring crew

Photo 3 –Core hole

Note: Paint chip samples were taken prior to the photographer being on-site.

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Appendix C

Pavement Extraction Data and Ferrous Content

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NHDOT Pavement Paint Study
Appendix C - Pavement Core Extraction Results
ASTM D2172 Standard Test Methods for Quantitative Extraction of Bitumen From Bituminous Paving Mixtures

Source: NHDOT Materials Research Laboratory
July 2013

Core #		Whitefield-1	Whitefield-4	Concord-2	Keene-1	Keene-5	Keene-6	Claremont-2	Claremont-4	Claremont-5	Laconia-2	Laconia-3	Average	Standard Deviation	FAA P401 Gradation 2
Tot. Core Thickness (in)		3.188	3.438	3.188	4.250	4.000	4.750	2.500	3.000	3.375	4.375	4.750			
Surface Mix Thickness (in)		1.500	1.813	1.625	2.880	2.000	2.625	2.500	1.375	1.875	2.188	2.375			
Nominal Sieve Opening	**Sieve Designation**	**PERCENT PASSING**											**COMPARISON VALUES**		
31.5 MM	1-1/4in														
25 MM	1 in.										100.0				-
19 MM	3/4in.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	100.0	99.99	0.0	100
12.5 MM	1/2in	98.1	100.0	91.5	86.2	84.3	98.9	98.6	86.4	90.4	81.0	99.2	92.24	7.0	79-99
9.5 MM	3/8in.	86.1	99.4	80.4	71.4	70.3	83.1	84.4	71.2	81.1	66.7	89.4	80.32	9.8	68-88
4.75 MM	No. 4	60.5	69.4	58.5	57.8	53.7	56.6	60.1	57.5	66.5	51.1	64.6	59.66	5.4	48-68
2.36 MM	No. 8	44.4	46.7	42.9	41.9	39.0	40.0	42.6	42.6	45.8	40.0	48.8	43.15	3.0	33-53
1.18 MM	No. 16	32.4	32.9	31.2	28.2	26.0	27.7	28.2	27.9	29.7	31.5	36.8	30.23	3.1	20-40
.600 MM	No. 32	20.8	22.1	22.4	19.8	18.0	19.7	18.3	18.1	19.0	24.1	26.5	20.80	2.7	14-30
.300 MM	No. 50	11.9	13.6	13.2	11.5	10.2	13.4	10.1	10.4	11.1	15.3	15.3	12.36	1.9	9-21
.150 MM	No. 100	7.0	8.2	7.1	6.7	6.1	7.9	6.1	6.1	7.0	7.2	7.0	6.95	0.7	6-16
.075 MM	No. 200	3.9	4.1	4.1	4.2	3.8	3.2	4.0	3.5	4.3	2.9	2.9	3.72	0.5	3-6
Asphalt Content (%)		5.54	6.20	5.58	5.46	5.13	5.90	5.96	5.30	5.84	5.15	5.87	5.63	0.4	5-7.5

MM - Milimeters

Note: Values in red are outside the range of FAA P401 Gradation 2

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Percentage of Ferrous Material in Sample Portion Passing #4 Sieve

Sample #	Total Sample wt. (g)	Weight Retained on #4 sieve (g)	Weight Passing #4 sieve(g)	Weight Passing #4 ferrous material (g)	% Ferrous material in portion passing #4 sieve
Whitefield-1	1620	640	980	54	5.5
Whitefield-4	1759	539	1220	86	7.0
Concord-2	1786	741	1045	5	0.5
Keene-1	2595	1095	1500	104	6.9
Keene-5	2363	1093	1270	128	10.1
Keene-6	2849	1238	1611	93	5.8
Claremont-2	2789	1112	1677	56	3.3
Claremont-4	1608	683	925	76	8.2
Claremont-5	2270	760	1510	203	13.4
Laconia-2	2330	1139	1191	34	2.9
Laconia-3	2584	914	1670	17	1.0

Method to achieve the values above consisted of stirring a magnet into the material for approximately 15 minutes.

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Appendix D

Analysis of New Hampshire Airport Pavement Paint Staining

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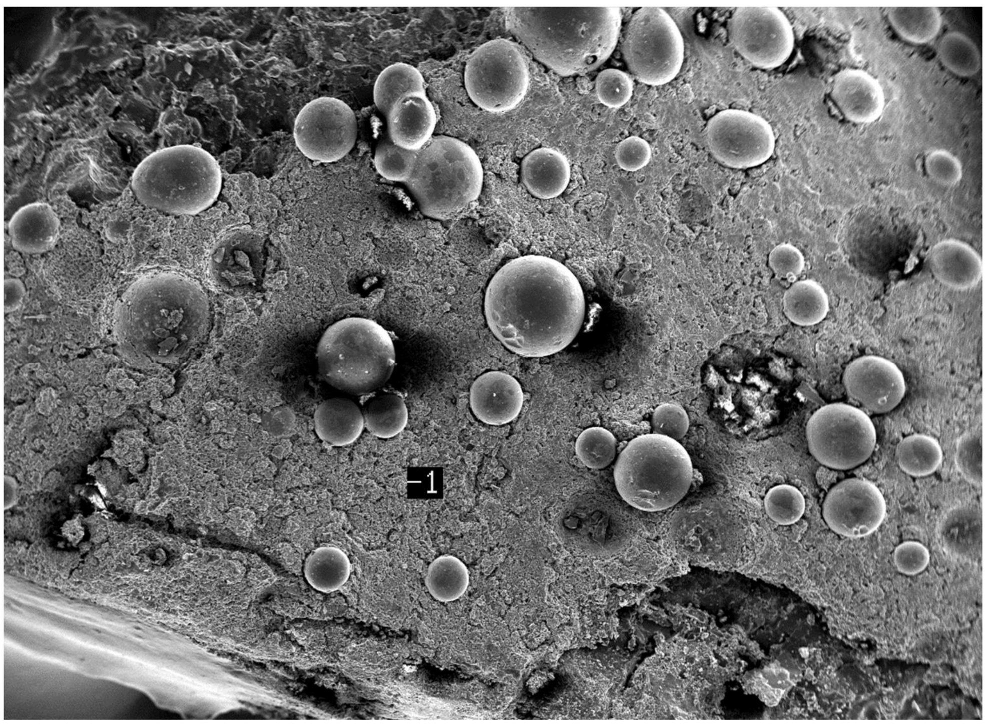
Analysis of New Hampshire Airport Pavement Paint Staining

by

David Gress



August 2014

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TABLE OF CONTENTS

BACKGROUND

The NHDOT has become aware of the presence of rust like stain present on NH airport pavement paint markings. Markings on airports follow a detailed plan depending on where the marking is located within the airport so it is essential the original colors are permanent so as to convey the proper meaning to the aviation users. Markings that become stained could be easily misinterpreted and are therefore a potential danger for aviation users. Maintenance as well as aviation safety is affected by staining because of the need to repaint the affected areas more often than normal.

SCOPE AND DESCRIPTION OF WORK

The scope of the work consists of positively identifying the cause of the paint staining. To accomplish this goal field samples of paint chips and cores were obtained for laboratory analysis from five selected New Hampshire Airports, Concord (CON), Claremont (CHN), Keene (EEN), Laconia (LCI), and Whitefield (HIE). The laboratory analysis included using the Scanning Electron Microscope (SEM) to obtain photographs of various specimens obtained from field chips and cores and Elemental Analysis by use of an Energy Dispersive X-Ray Spectroscopy technique (EDS). Petrographic analysis was conducted on aggregates obtained from extracting selected cores of the asphaltic surface mix. An accelerated oxidation aging test was performed on the magnetic aggregate to force rusting.

LABORATORY PROCEDURES AND RESULTS

Laboratory Specimens

The five airports were visited and chip samples were obtained by chiseling small areas of the asphalt which contained selected degrees of staining ranging from no visible staining to very heavy staining. Areas were marked for cores to be taken at a later date by NHDOT.

Figures 1 and 2 (see Appendix D1 for Figures) show a core obtained from Concord. Claremont chips and cores are presented on Figures 3 through 10. Chips and cores obtained from Keene are shown on Figures 11 through 15. Figures 16 through 21 show the photographs of the chips and cores obtained from Laconia. The Whitefield chips and cores are shown on Figures 22 through 29. These airports were selected based on the known presence of paint staining

SEM and EDS

The scanning electron microscope used in this study was an Amray 3300FE field emission SEM. This SEM creates a three-dimensional visual interpretation and produces high resolution images. It has a PGT EDS system for elemental analysis. The depth of the scanning electron microscope is nearly 300X that of a light microscope. Its magnification range is between 15X and 100kX. This microscope has accelerating voltages from 1-25kV. The frame buffer of the microscope is 2048 x 2048 and the resolution is 1.5nm. Selected samples from the chips and cores obtained from the five airports were mounted on stubs and sputter coated with gold prior to being evaluated on the SEM.

SEM and EDS Results

Laconia

Glass beads are easily identified on the Laconia paint chip shown in Figures 30 and 31. The elemental analysis of the overall surface shows the major components of the glass beads, (Silica at 14.7 % see Table 1) the paint (Titanium at 12.5 % and some minor components of Sodium at 2.46 %, Aluminum at 2.9 %, and Calcium at 3.0 %) and the major staining component (Iron at 36.42 %). Refer to Appendix D2 for SEM and EDS Table Results. A close up of the paint is shown in Figure 33 where the iron has reduced to 6.4 %. A high magnification (1000X) of the paint as shown in Figure 35 shows the extent of the high iron stain coverage (74.0 %). Similarly the EDS spectrum of Figure 41 shows the extent of a high iron content (47 and 58 %) on the surface of the paint. Moving away from the apparent source of staining shows the iron content to decrease (see Figures 44 and 45 and Table 7) to 14.1 %. These data show the staining to be iron and its content to vary depending on the location on the chip.

Claremont

Data obtained from Claremont chips are shown on Figures 46 through 64. These results are similar to those of Laconia except some showed very high concentrations of iron. Figures 3 through 6 shows photos of chips with very intense staining. This is apparent in the photos that show the original color of the paint where it was exposed during its removal from the pavement. EDS data shown on Figures 48, 50, 53, and 55 (see data in tables 8 through 11) show the iron contents to be above 70 % which is consistent with the intense rust like color on the paint chips. Of special interest is Figure 60 which shows an area where the paint has peeled off (see location 2). The surface paint located at position 1 has an iron content of 15.7 % which shows it has been stained. The area where the surface paint chipped off during the preparation of the sample shows an iron content of 74.4 %. This is significant because it is under the surface of the paint. Such suggests the paint may be causing the rust to accumulate under its substrate, presumably caused by migration of moisture towards a semipermeable membrane.

Concord

The Concord paint chip was similar to position one at CHN and EEN showing presence of iron at 15.9 % on the overall elemental scan on Figure 66 (see Table 17).

Keene

Position 1 on the Keene paint chip shown on Figure 69 is near a source of staining had an iron content of 17.1 % while position 2 further away from the stain had only 0.98 % iron.

Whitefield

Paint chips from Whitefield showed variation in iron ranging from a low of 5.34 to a high of 73.37 % as shown on Figures 71 through 80 (see Tables 21 through 25).

Extraction of Cores

The surface asphaltic concrete of the cores obtained from the five airports were extracted by the New Hampshire Department of Transportation (NHDOT) so as to determine the mix properties as well as to recover the aggregates. During the sieving it was discovered that some of the aggregates from each source were magnetic. The extracted and magnetic aggregates were obtained from the NHDOT for observation and testing. This was an excellent opportunity because only minerals that contain iron are magnetic and therefore these aggregates had to be the source of the iron staining.

Magnetic minerals

The major rock-forming magnetic minerals are the following iron oxides: the titanomagnetite series, $xFe_2TiO_4 \cdot (1 - x)Fe_3O_4$, where Fe_3O_4 is magnetite, the most magnetic mineral; the ilmenohematite series, $yFeTiO_3 \cdot (1 - y)Fe_2O_3$, where α-Fe_2O_3 (in its rhombohedral structure) is hematite; maghemite, γ-Fe_2O_3 (in which some iron atoms are missing in the hematite structure); and limonite (hydrous iron oxides). They also include sulfides—namely, the pyrrhotite series, $yFeS \cdot (1 - y)Fe_{1-x}S$. (see: http://www.britannica.com/EBchecked/topic/505970/rock/80202/Magnetic-minerals-and-magnetic-properties-of-rocks) Source: From T. Nagata, ed., *Rock Magnetism,* Maruzen Co., Tokyo (1961).

Magnetic Aggregate

A group of the coarse size magnetic aggregates from each airport were compiled from the extracted from the cores. Figure 81 shows the ½" magnetic aggregates from Concord. The Claremont ½" magnetic aggregates are shown on Figure 82. Keene, Laconia, and Whitefield ½" magnetic aggregates are shown on Figures 83 through 85 respectively. Color, texture, visual crystallinity, grain size and shape were used to select unique aggregates for petrographic analysis. The rocks in general were variable so to make sure all possible minerals were included a total 38 different aggregate particles were selected for petrographic analysis. A selection of aggregates from each source based on visual differences discussed above included twelve from Claremont, five from Concord and fifteen from Whitefield. None were selected from Laconia for two reasons, a petrographic analysis is available in a report previously submitted entitled "Laconia Municipal Airport Pavement Evaluation Preliminary Report", October 22, 2012, by David Gress, Portsmouth, NH. The second reason is that the Pike source of aggregate is no longer being used for HMA due to known deterioration issues encountered at the Laconia airport.

A sample of the smaller magnetic aggregates from each airport was compiled and placed in a plastic cup approximately 2" in diameter and a low viscosity clear epoxy was used to pot the particles. After the epoxy cured the cylinders were cut into thin disks and polished using water on a rotating abrasive wheel. An interesting observation was made when the disks were observed under a normal light microscope. At the micro level it was noticed that some rusting of the aggregate particles occurred during polishing the disks with water. The disks were repolished using ethanol alcohol instead of water to prevent any rusting of the aggregate. Side A of the Claremont small magnetic aggregate epoxy disk, after polishing with ethanol alcohol, is shown in Figure 86. The observation of rusting during polishing with water led to the development of an aging test to see if the magnetic particles could be forced to rust under laboratory conditions.

Magnetic Aggregate Laboratory Aging

Rocks found in nature commonly decompose into simpler components when subjected to weathering and time. Of special interest are rocks that contain iron such as those recovered during the extraction. Weathering of iron in aggregates is basically equivalent to the oxidation of iron. The mechanism of oxidation, referred to as rusting, consists of the reaction of oxygen in the presence of water with iron. Rust is a generic term to describe different oxides of iron, $Fe(OH)_2$, $Fe(OH)_3$, $FeO(OH)$, and the most common form $Fe_2O_3{:}H_2O$.

A laboratory test was designed to take advantage of the thermally activated mechanism. The process occurs when oxygen disolves in water in the presence of iron at a favorable temperature.

The laboratory test consisted of placing the polished epoxy disks of smaller magnetic aggregate over water in a sealed plastic container held at 100 ^{o}F. The epoxy sealed all sides on the disk except for the polished faces which simulates what happens when the HMA surface mix is placed, namely that only the surface has access to moisture and oxygen.

Figure 87 shows Claremont disks sides B and D placed on 1”x1”x1/4” stainless plate such that the disks were above the water line and subject to humidity only. The containers were placed in an oven held at 100 ^{o}F for 3 months. Figure 88 shows disk B/A after 3 months of storage over water held at 100 ^{o}F. It was noted that rust staining occurred on the plastic container where the stainless steel plate had been. The bottom side of the B face (side A) also showed rust where it had been placed on the stainless steel plate as shown on Figure 89. In all cases the stainless steel showed no signs of rust. The rust originates in the aggregate then becomes mobile and deposites elsewhere similar to what happens in the field on the paint markings and the HMA surface. A close up of the before and after soaked for 3 months is shown on Figure 90.

Petrographic Analysis

A petrographic analysis was performed on the aggregates by Dr. Wallace A. Bothner, PhD, PG240, Professor Emeritus of Geology, University of New Hampshire.
The report is provided in Appendix D3 – Petrographic Analysis.

CONCLUSIONS

Rust staining of the magnetic aggregates was shown to be reproducible under accelerated laboratory environment of temperature and humid air. The rocks associated with the staining were found to be iron bearing magnetic minerals, very typical of New Hampshire aggregates. From a petrographic view point the potential aggregates associated with the staining are those occupied by opaque iron oxide, iron sulfide, and iron oxyhydroxide minerals. These minerals are directly associated with other ferromagnesian minerals such as amphibole and biotite. A recent study has shown biotite degradation to be the primary issue of HMA surface deterioration at the

Laconia airport. The felsic minerals quartz and feldspar were found to not be associated with staining.

RECOMMENDATIONS

In that dissociation of iron from iron bearing minerals causes staining suggests that any method of minimizing the presence of moisture and oxygen on the HMA surface mix is expected to hinder potential staining. Such methods could include sealing the surface and/or applying a hydrophobic treatment to lower the internal moisture content within the asphaltic concrete.

A guaranteed solution of preventing staining is to specify aggregates high in felsic minerals like quartz and feldspar while minimizing aggregates containing iron and sulfur. A potential testing procedure would be minimizing the amount of magnetic aggregates used in the surface HMA mix. It is not expected that the lower courses of HMA contribute to staining so no specification would be required for them.

Phase II Recommendations

Additional work is recommended to evaluate the effectiveness of selected treatment methods to prevent rusting of the aggregates on/within pavement paint. A field and laboratory testing program would consist of selecting two airports one in the southern portion of the state and the other in the northern so as to consider the effect of temperature. Existing sections of paint strips on each airport with the approximate same level of flatness (slope) would be treated as per the recommendations of this report. Additional sections could be selected for repainting prior to treatment as required. Additionally a companion laboratory testing program using samples of existing pavement paint removed from the selected airports after treated would be evaluated in a controlled laboratory environment. The intent would be to attempt to accelerate oxidation using various levels of temperature, humidity and possibly oxygen. Oxidation acceleration would allow treatments to be ranked for effectiveness. This laboratory experiment could also be utilized to test more treatment options prior to the actual field testing program such that only the more effective treatments be selected for field testing. The details of such testing would have to be developed and submitted for approval by the NHDOT.

APPENDIX D1 – Figures

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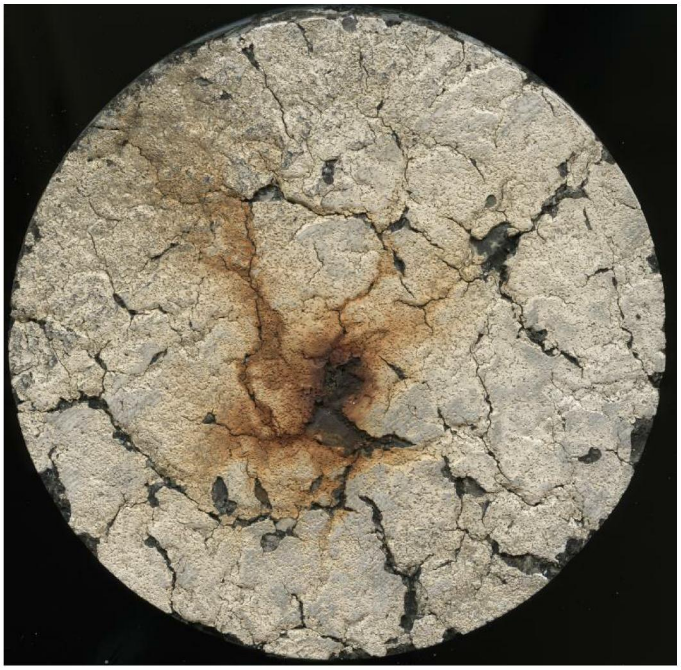


Figure 1 Concord core showing source of major iron staining

Figure 2 Close up of Figure 1 showing iron staining

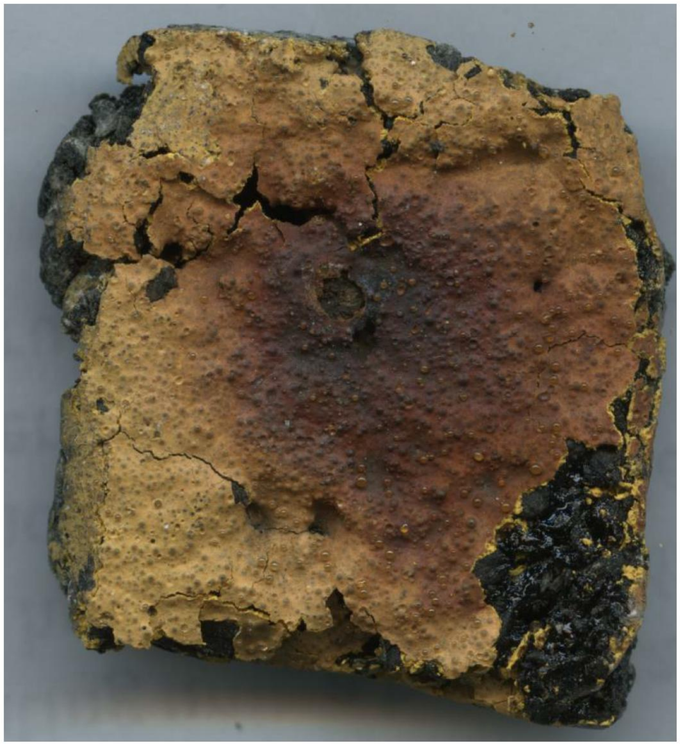


Figure 3 Claremont paint chip showing source of iron stain

Figure 4 Claremont paint chip showing uniform iron stain coating

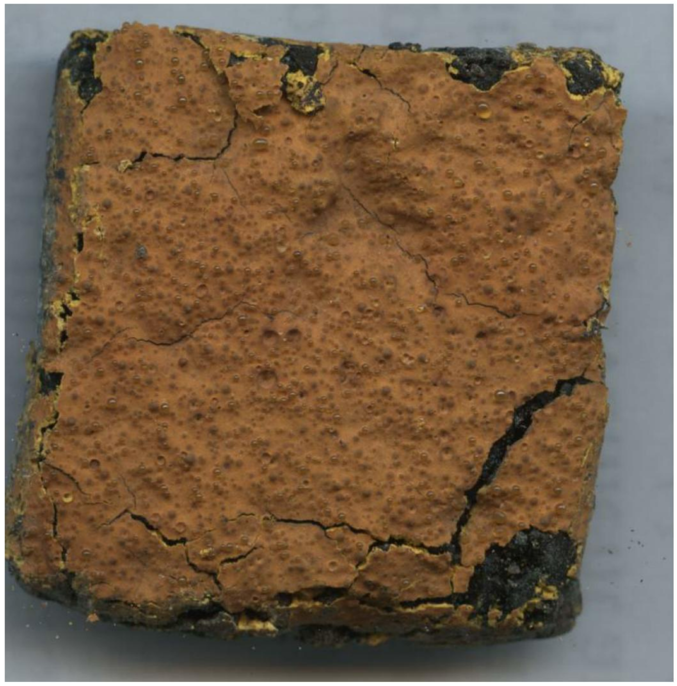


Figure 5 Claremont paint chip showing uniform iron staining (note original paint color at fractures)

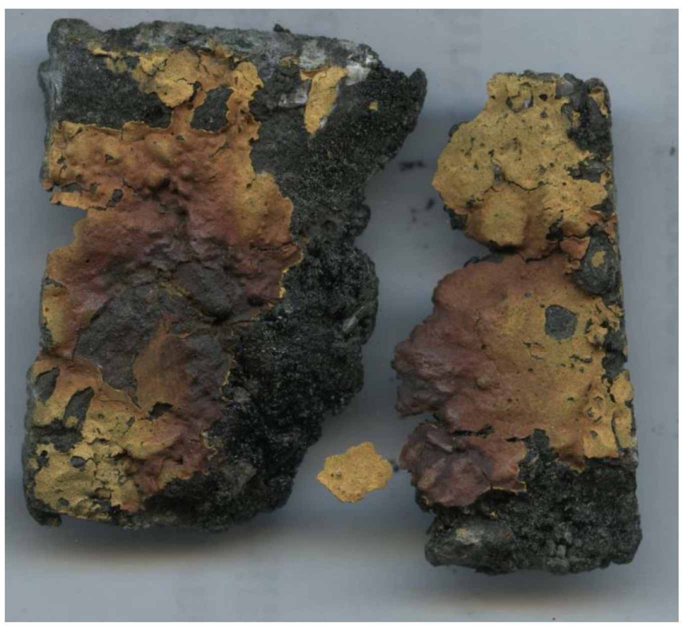


Figure 6 Claremont paint chip showing source of major iron staining

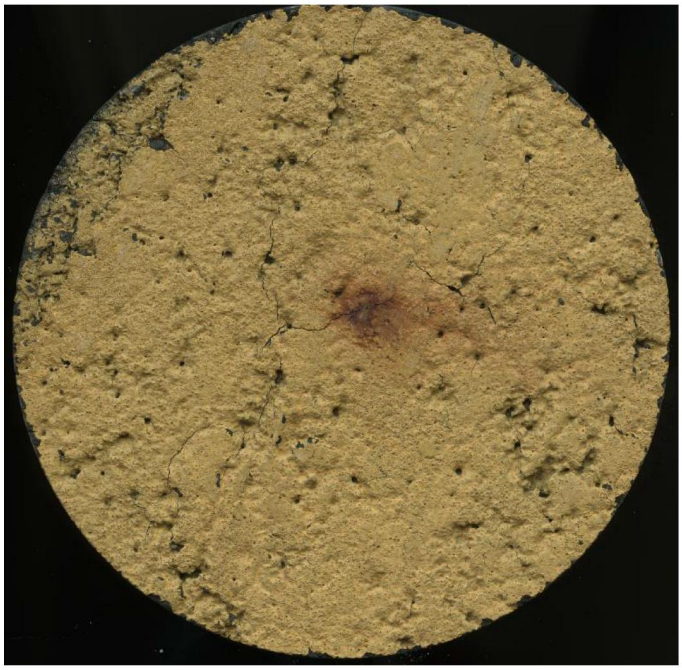


Figure 7 Claremont core showing iron stainimg

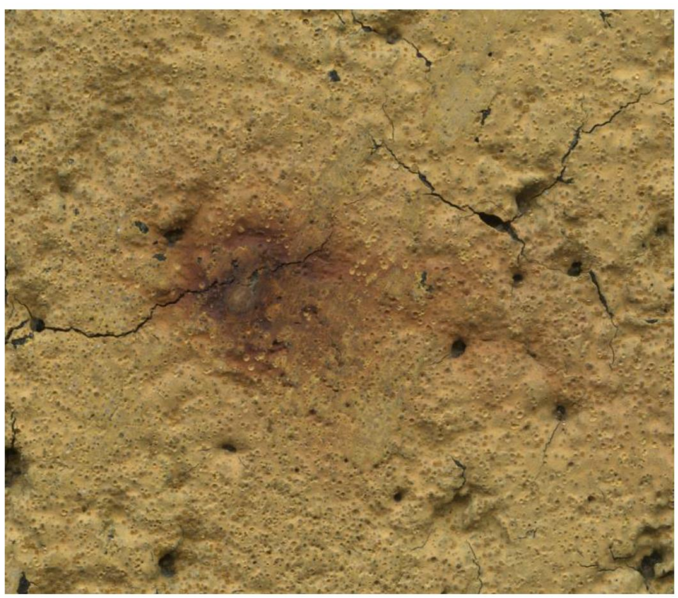


Figure 8 Close up of stain source on Figure 7

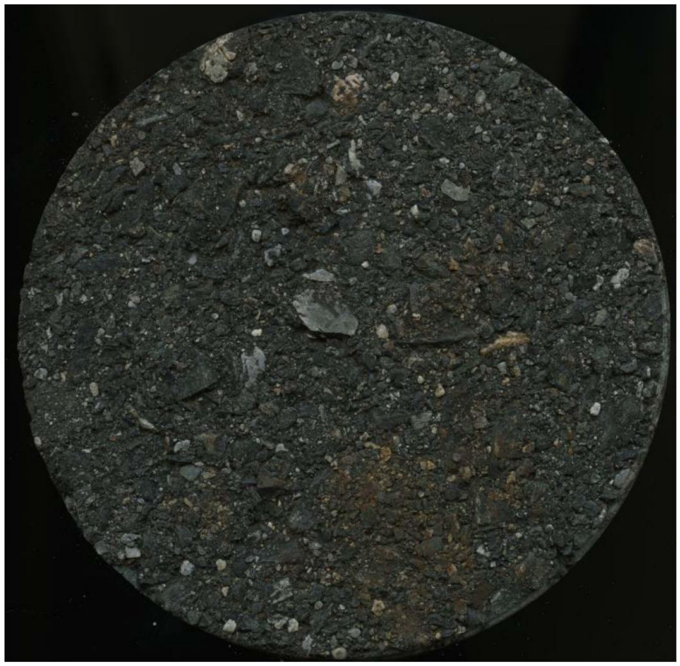


Figure 9 Claremont core without paint showing no obvious iron staining

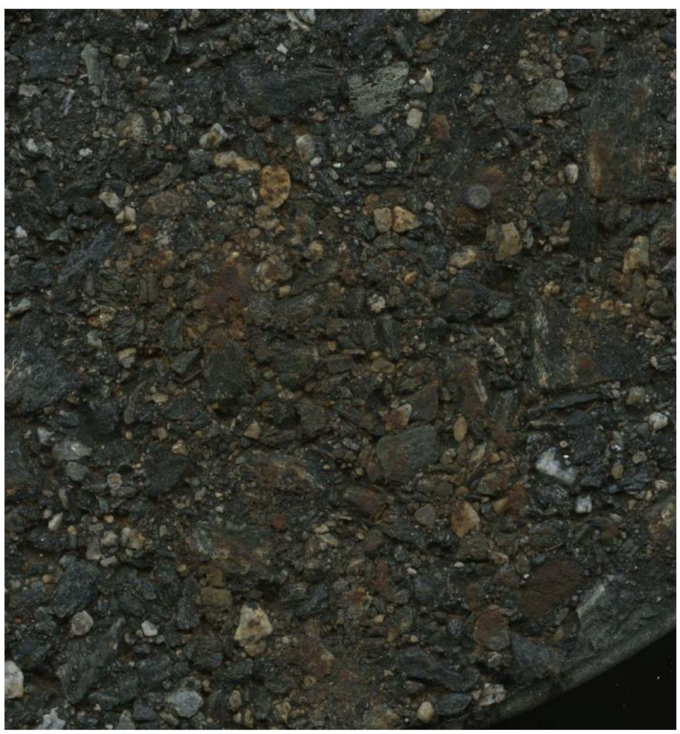


Figure 10 Close up of Figure 9 showing uniform iron staining of the exposed aggregate

Figure 11 Keene paint chips

Figure 12 Keene core showing source of iron staining

Figure 13 close up of stained area in Figure 12

Figure 14 Keene core showing source of stain area

Figure 15 Close up of stained area from Figure 14

Figure 16 Laconia paint chips showing iron staining

Figure 17 Laconia paint chips showing major iron staining

Figure 18 Laconia paint chips showing source of iron staining

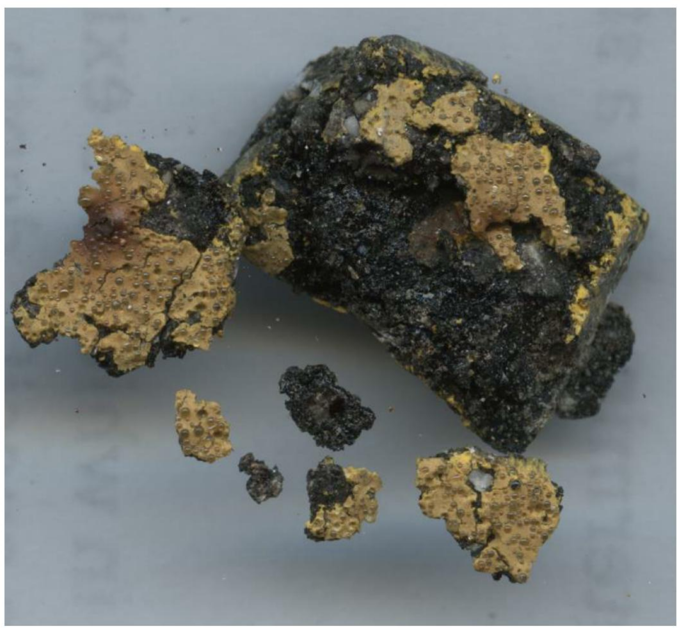


Figure 19 Laconia paint chip showing stained glass beads

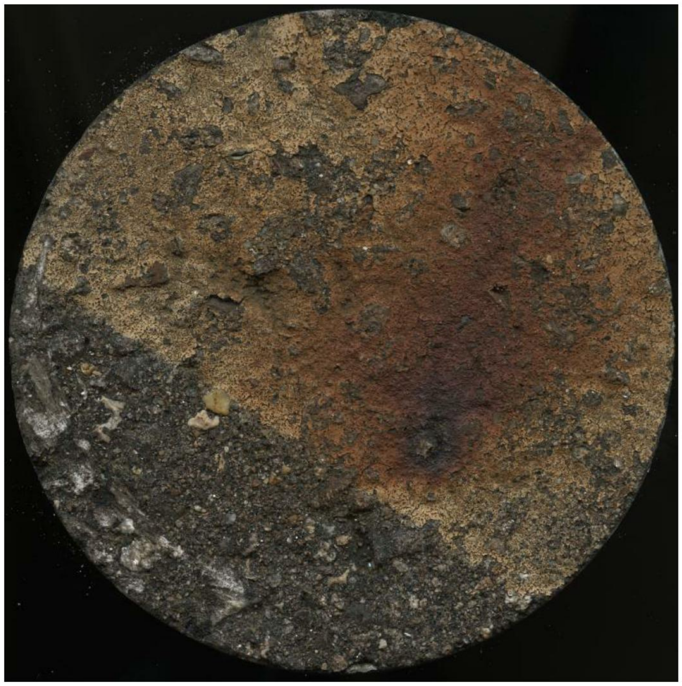


Figure 20 Laconia core showing source of iron staining

Figure 21 close up of Figure 20 showing major staining

Figure 22 Whitefield paint chip showing source of iron staining

Figure 23 Whitefield paint chip showing large area where staining emerged

Figure 24 Whitefield paint chip showing little staining

Figure 25 Whitefield paint chip showing small source of staining

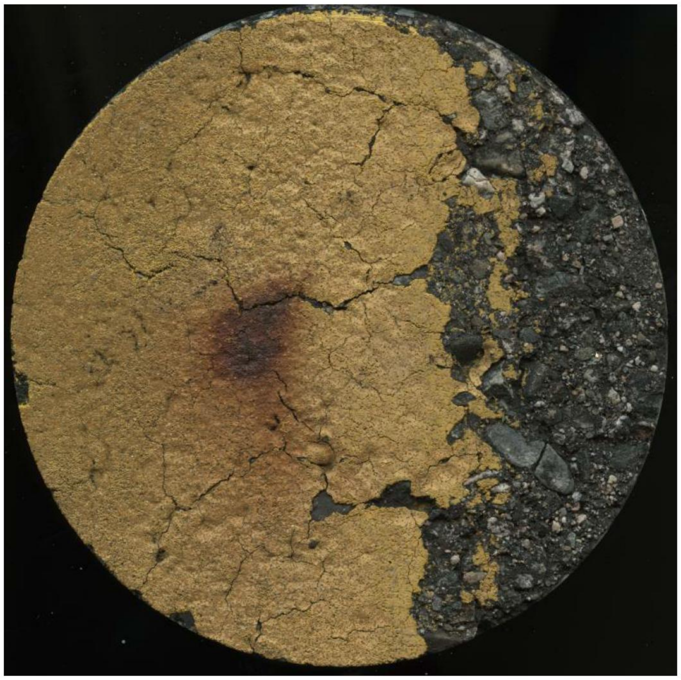


Figure 26 Whitefield core showing source of iron staining

Figure 27 Whitefield close up of Figure 26 note intensity of light color of paint under glass beads lost during coring

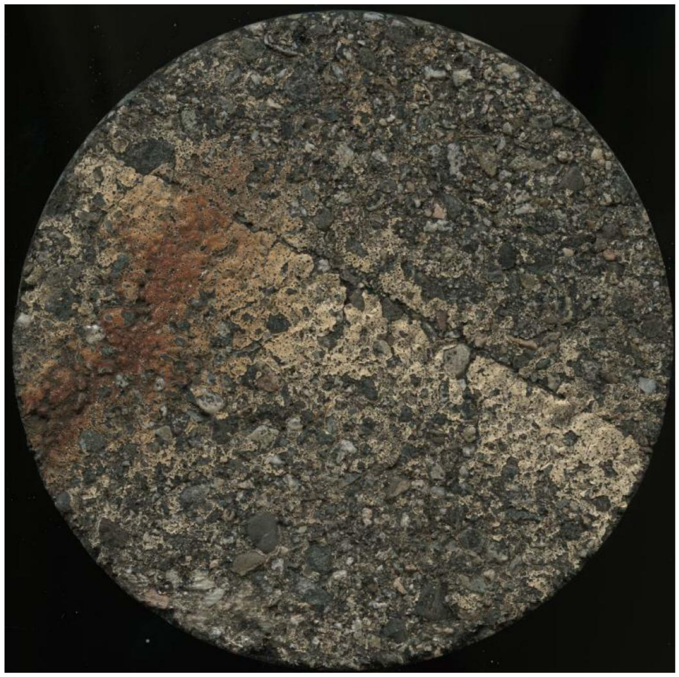


Figure 28 Whitefield core showing staining source

Figure 29 Close up of Figure 28 note degree of heavy staining

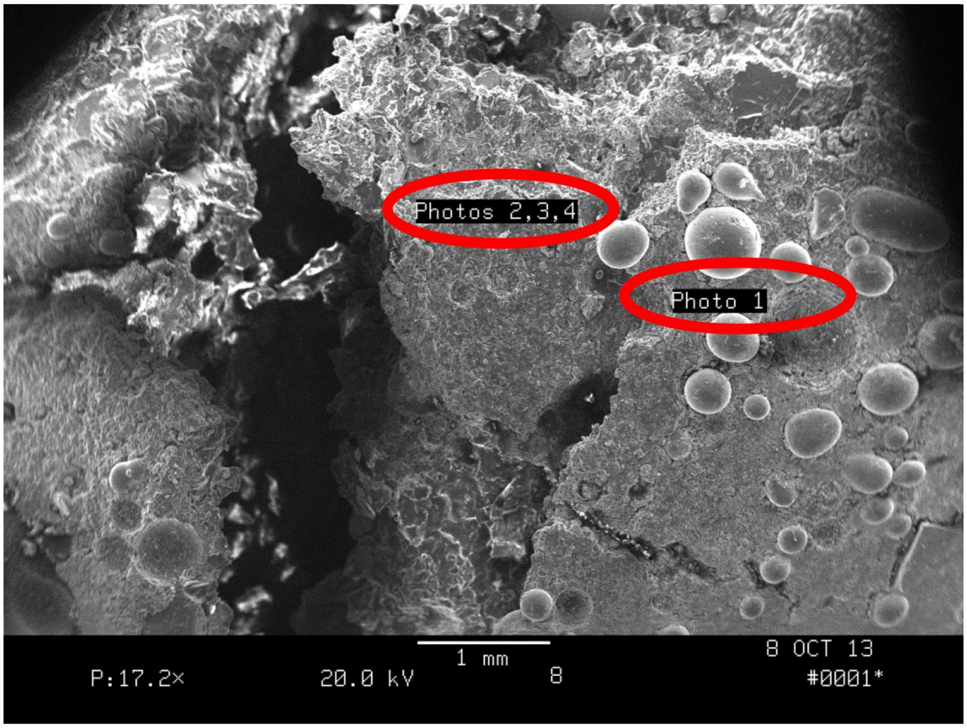


Figure 30 SEM photo of Laconia paint chip showing investigated areas

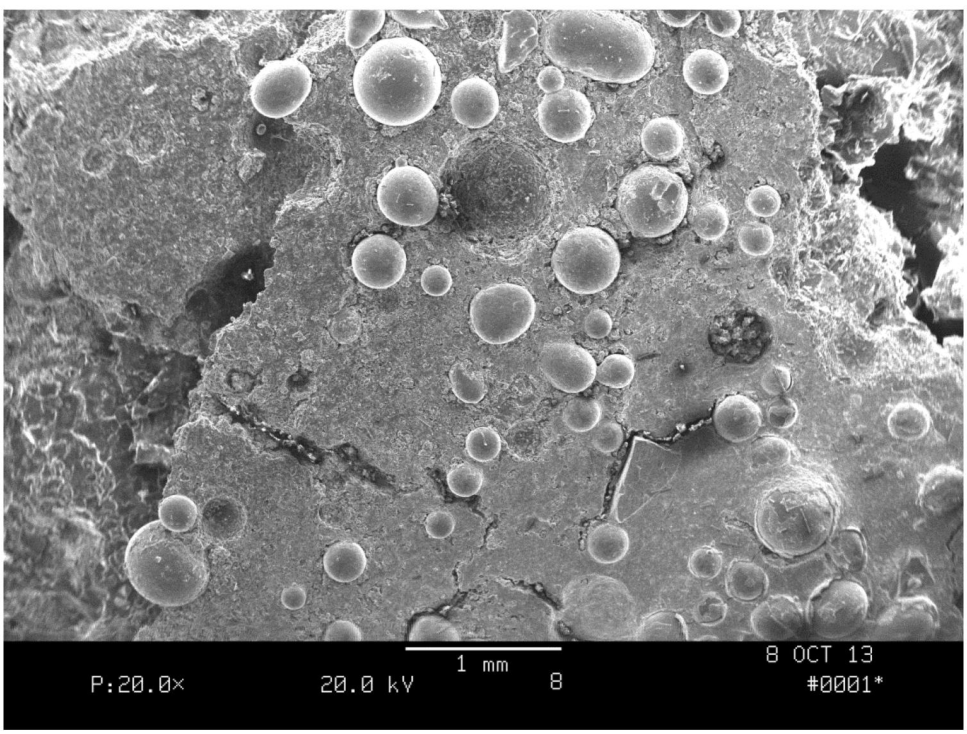


Figure 31 SEM photo of Laconia paint chip showing glass beads (see Figure 30 for location, Photo 1)

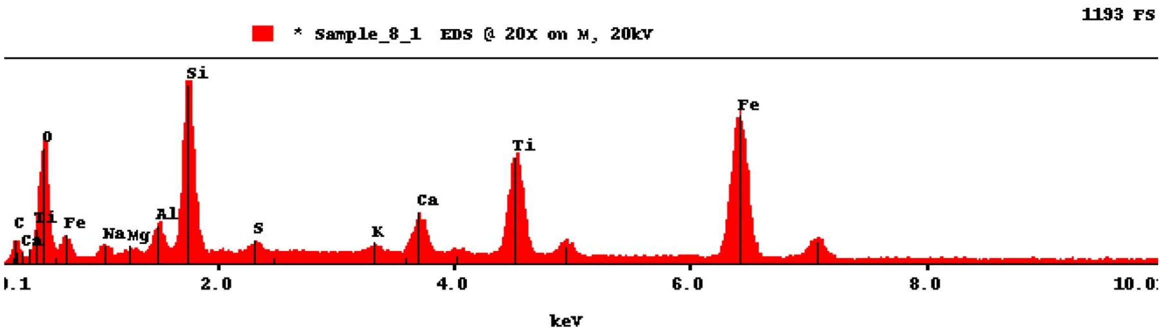


Figure 32 Laconia Elemental Spectrum for area shown in Figure 31 (see Table 1)

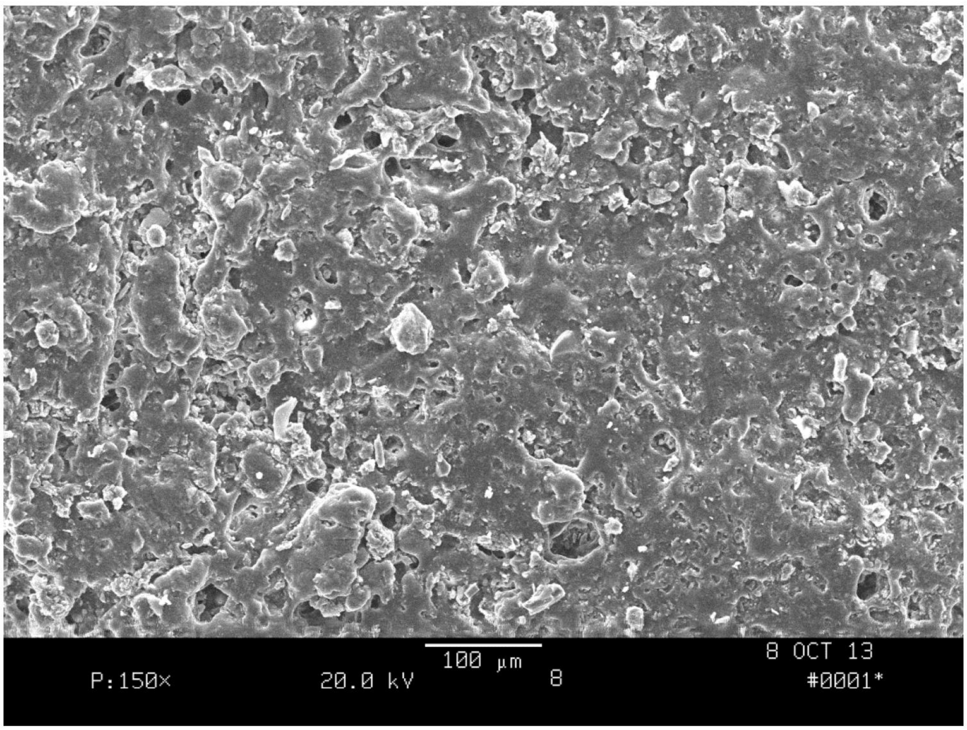


Figure 33 SEM photo of Laconia paint chip (see Figure 30 for location, Photo 2)

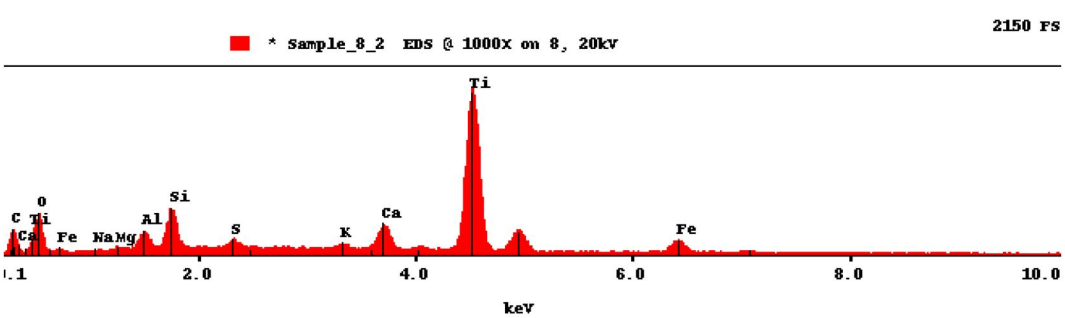


Figure 34 Laconia paint chip elemental spectrum for area shown in Figure 33 (see Table 2)

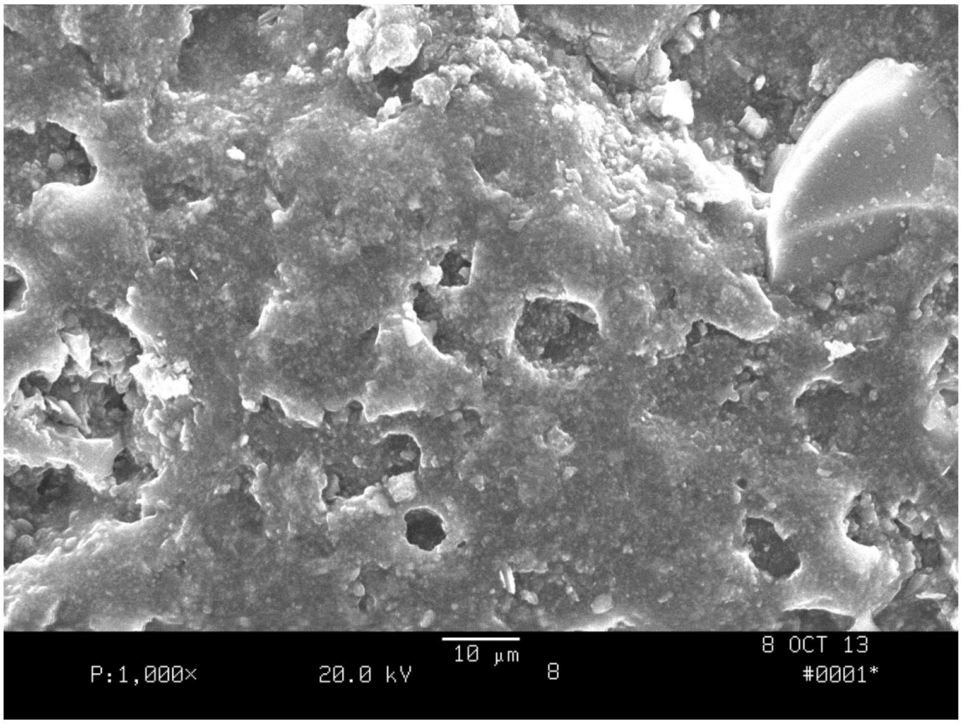


Figure 35 SEM photo (1000x) of Laconia paint chip (see Figure 30 for location, Photo 3)

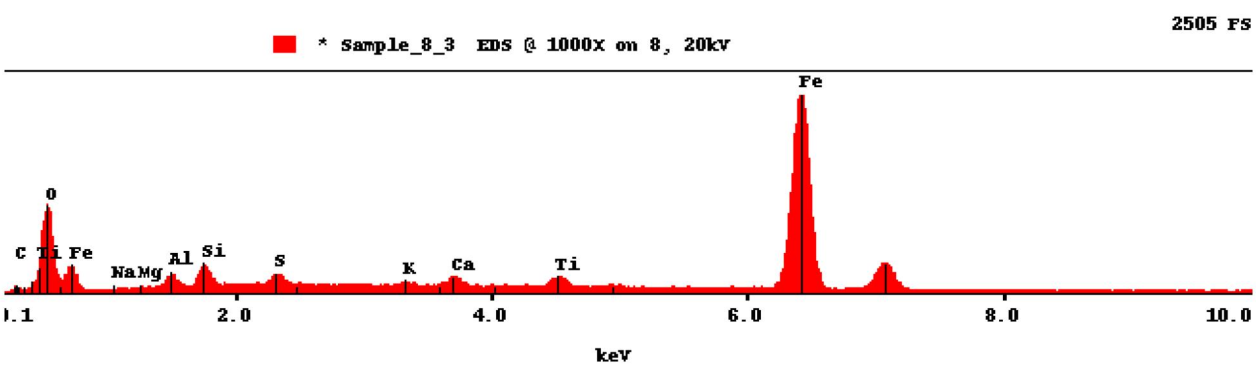


Figure 36 Laconia paint chip elemental spectrum for area shown in Figure 35 (see Table 3)

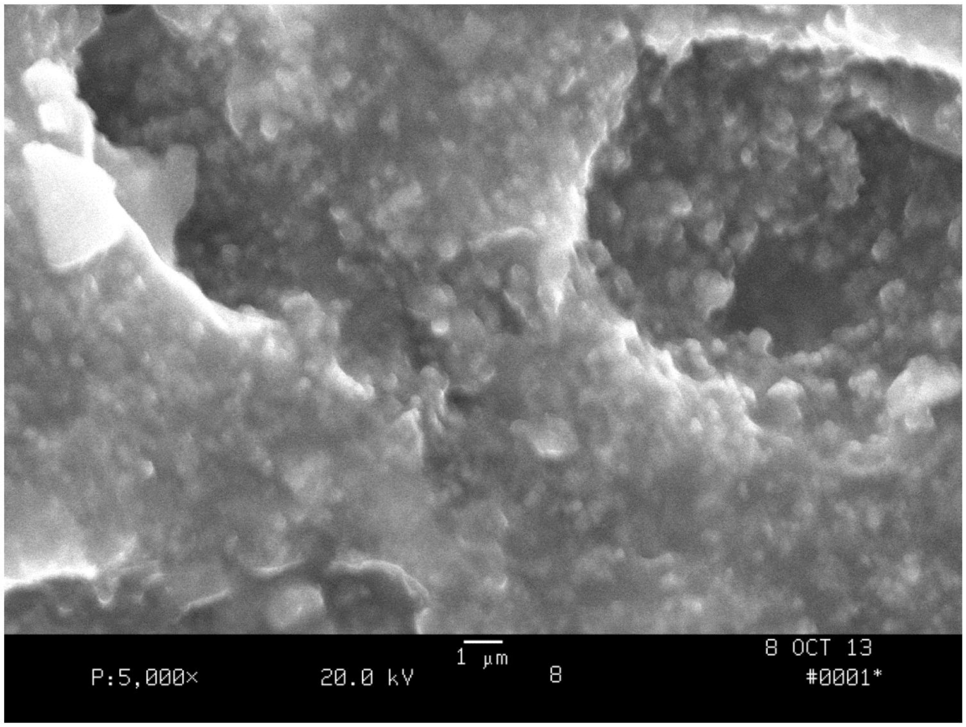


Figure 37 SEM photo (5000x) Laconia paint chip area shown in Figure 35

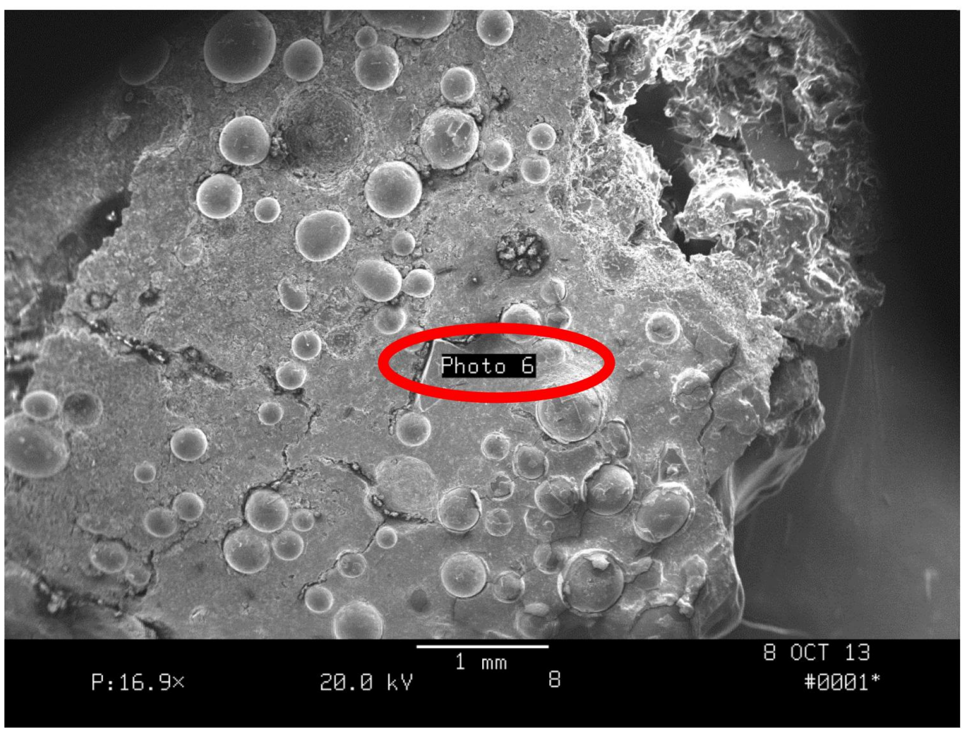


Figure 38 SEM photo of Laconia paint chip showing investigated area #6

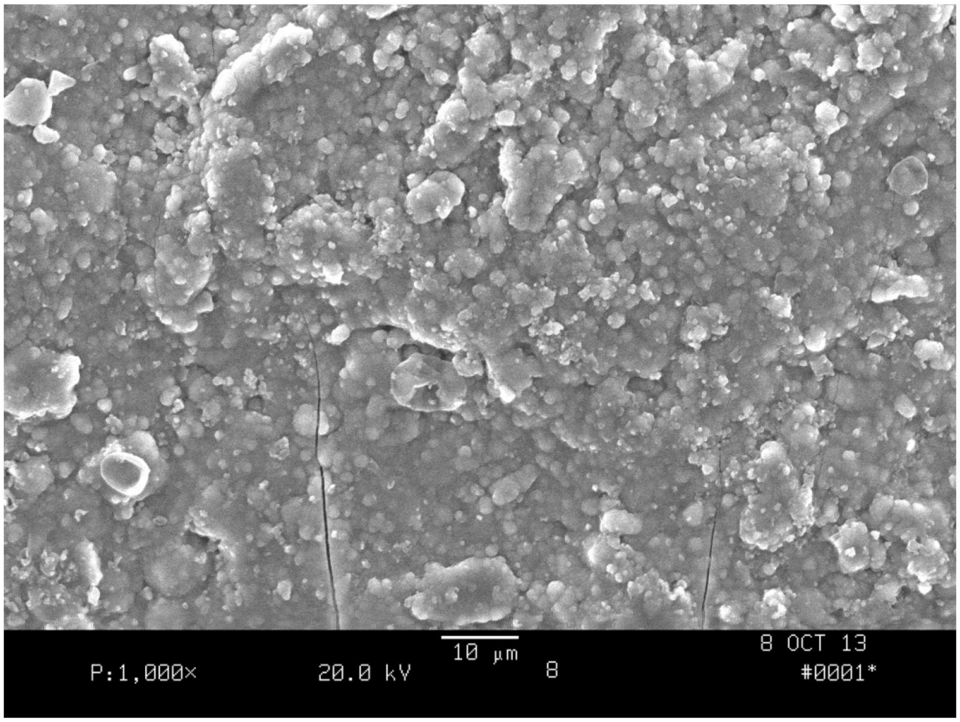


Figure 39 SEM photo (1000x) of Laconia paint chip (see Figure 38 for location, Photo 6)

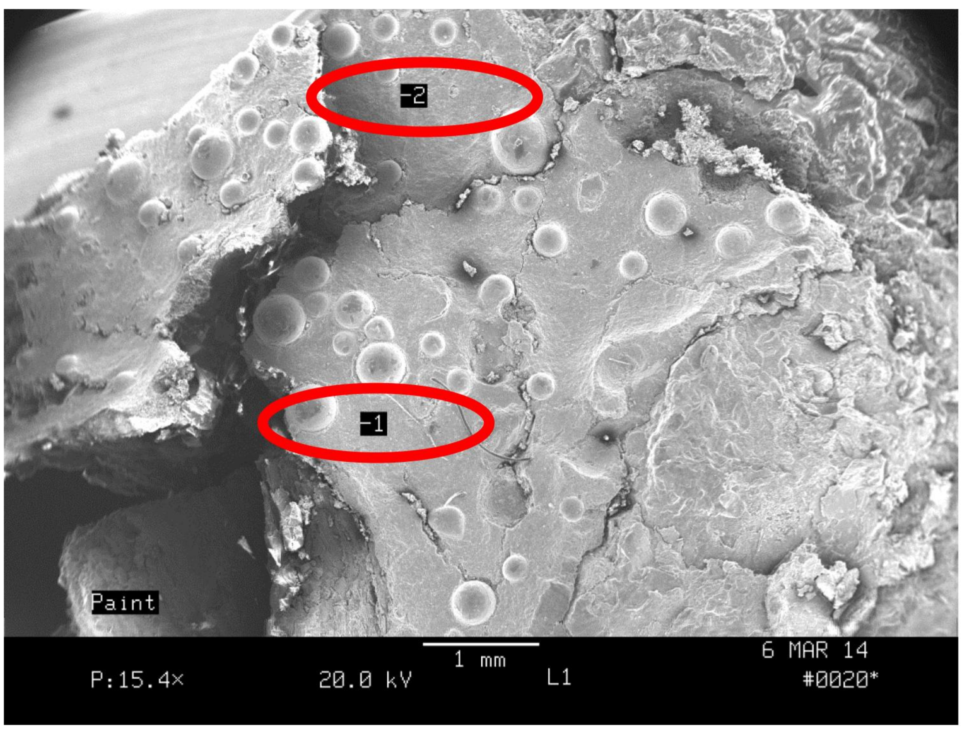
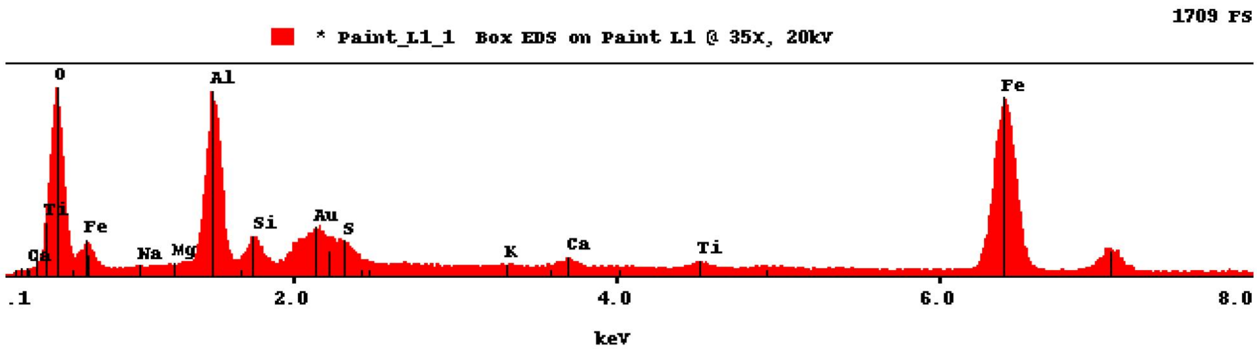


Figure 40 SEM photo of Laconia paint chip showing investigated areas 1 and 2

Location 1



Location 2

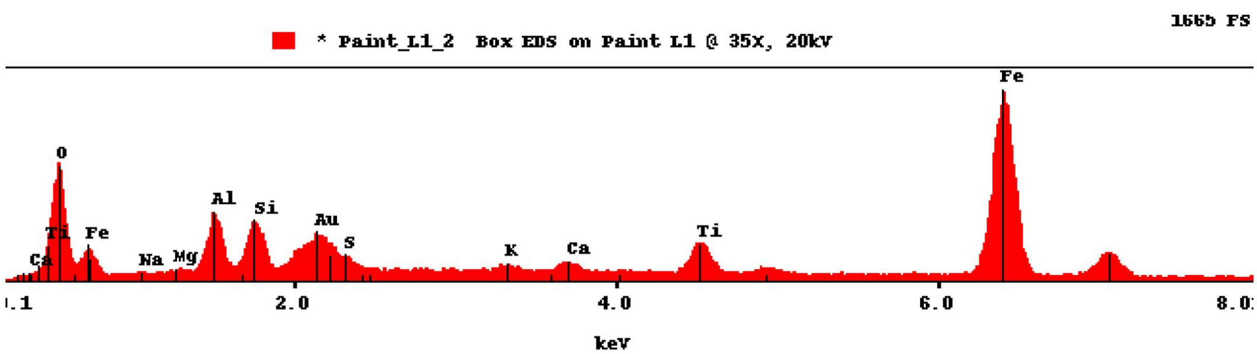


Figure 41 Laconia paint chip elemental spectrum for areas 1 and 2 shown in Figure 40 (see Table 4 & 5)

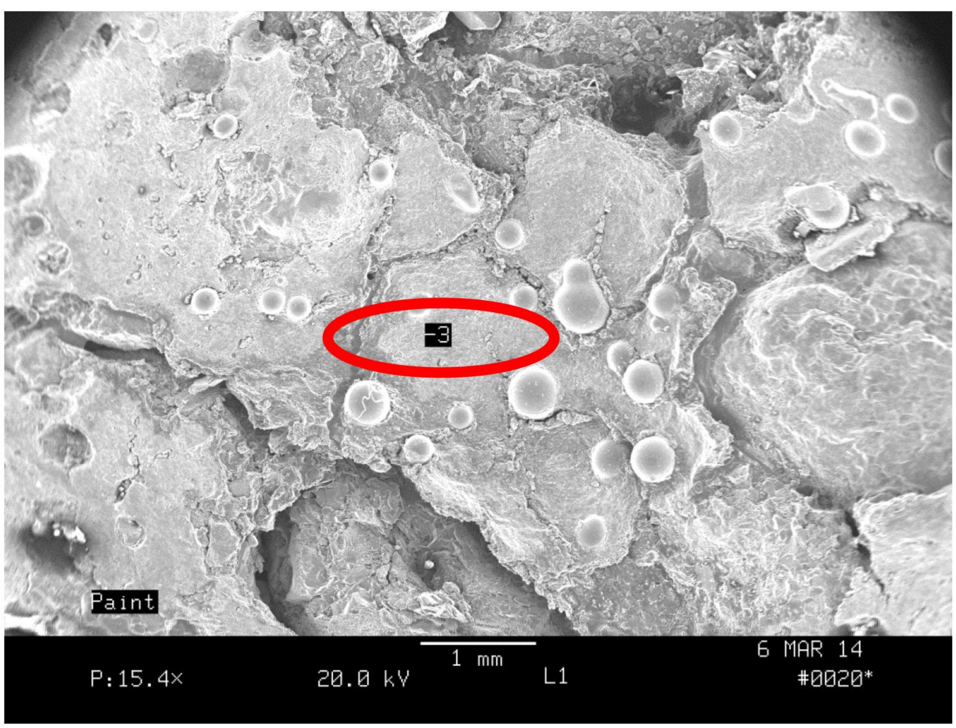


Figure 42 Laconia paint chip showing investigated area 3

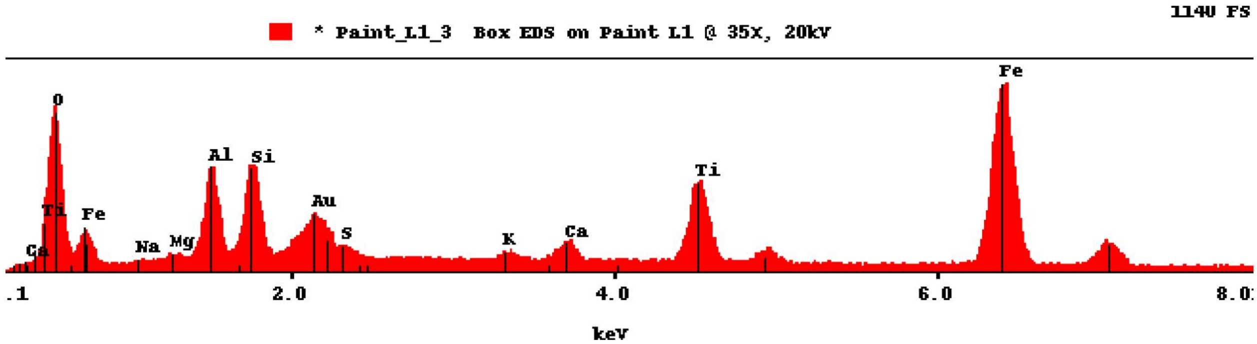


Figure 43 Laconia paint chip elemental spectrum for area 3 shown in Figure 42 (see Table 6)

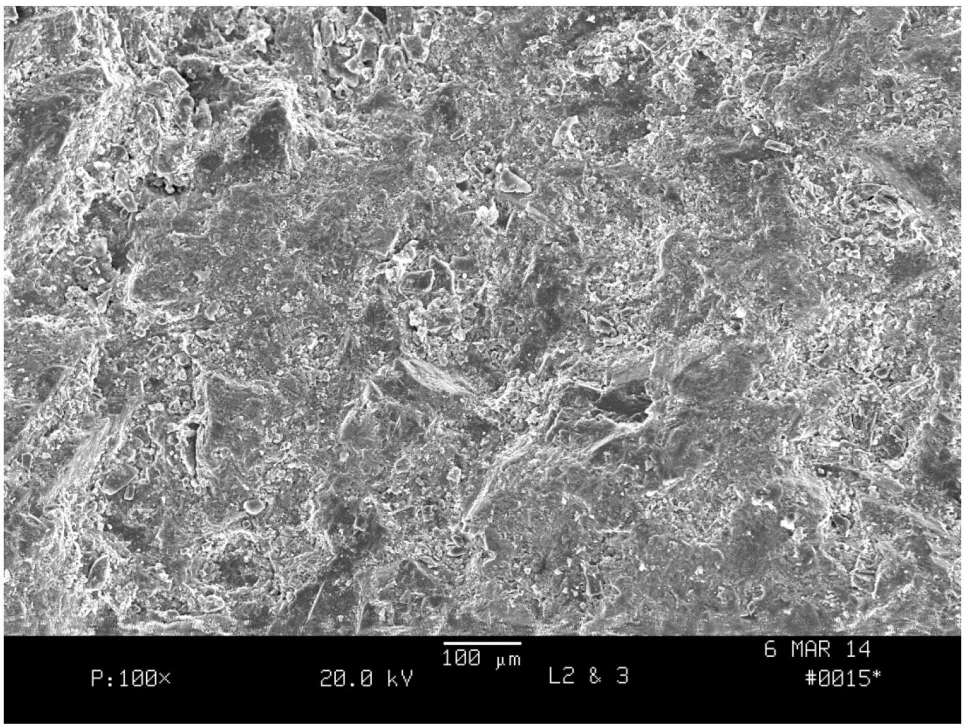


Figure 44 Laconia paint chip (100X) showing investigated areas 2 and 3

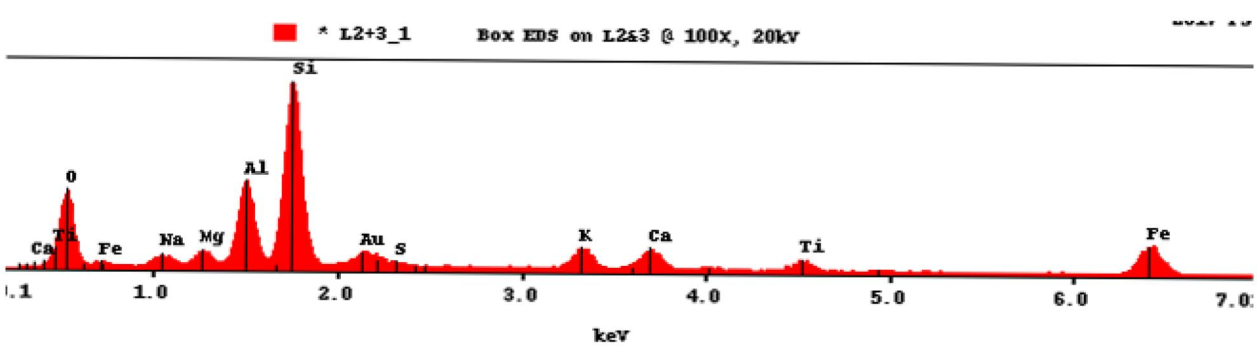


Figure 45 Laconia paint chip elemental spectrum for area 2 and 3 shown in Figure 44 (see Table 7)

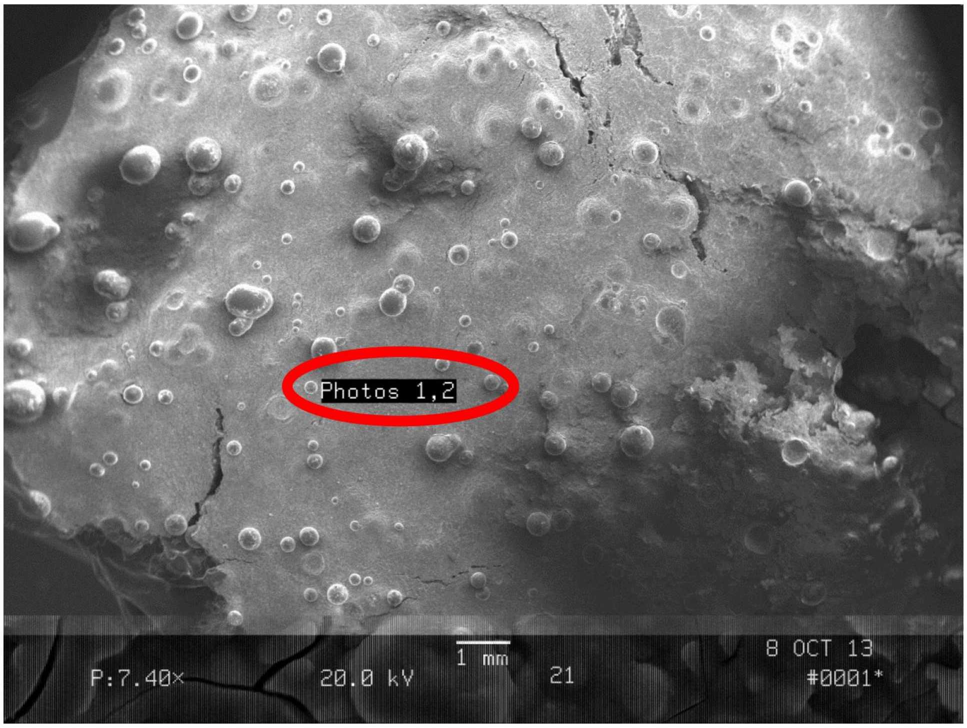


Figure 46 SEM photo of Claremont paint chip showing investigated areas 1 and 2

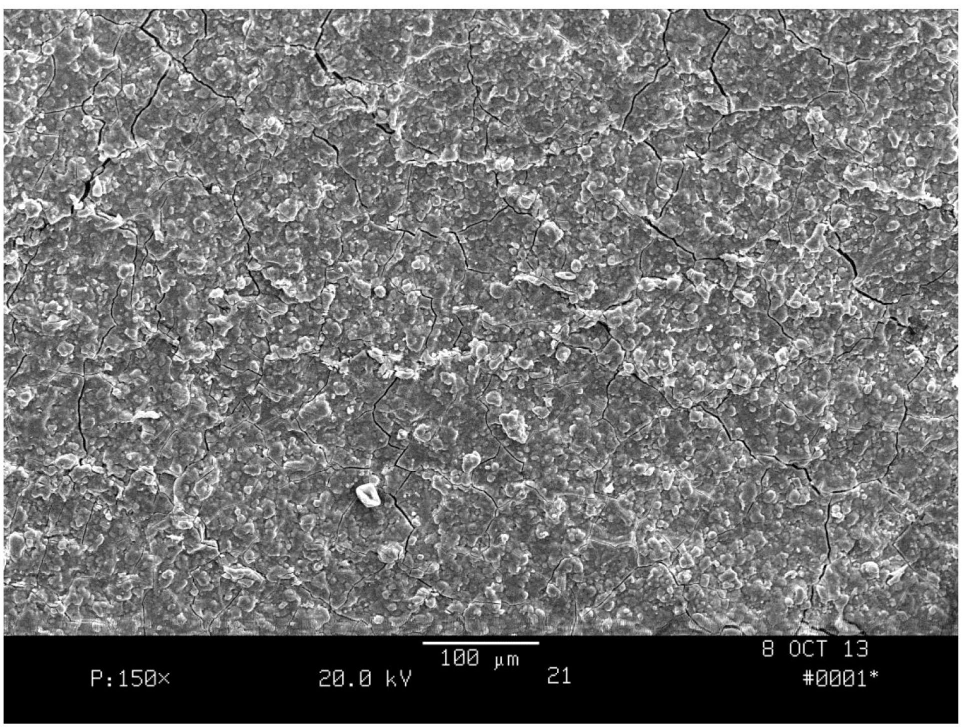


Figure 47 SEM photo (150X) of Claremont paint chip (see Figure 46 for location, Photo 1)

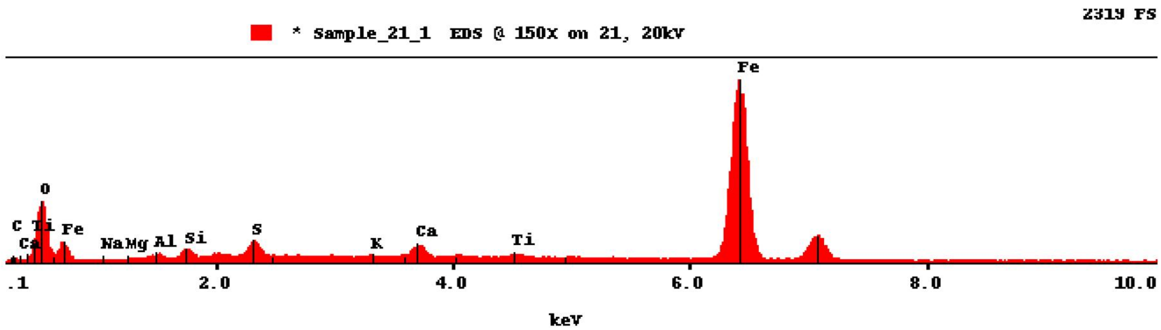


Figure 48 Claremont paint chip elemental spectrum for area shown in Figure 47 (see Table 8)

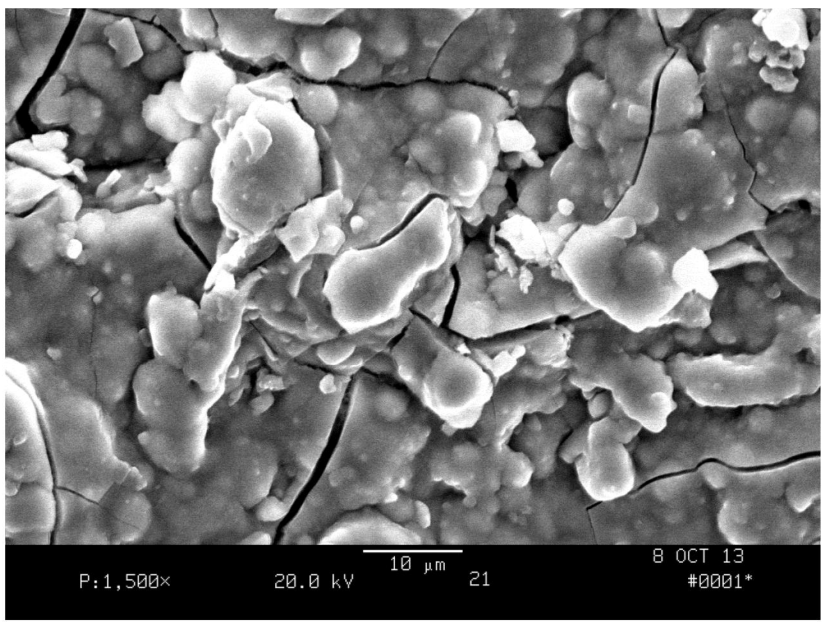


Figure 49 SEM photo (1500X) of Claremont paint chip (see Figure 46 for location, Photo 1)

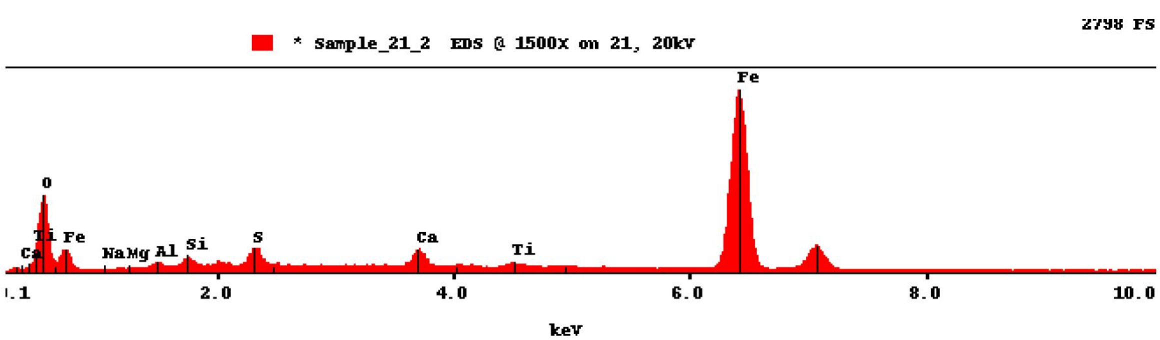


Figure 50 Claremont paint chip elemental spectrum for area shown in Figure 49 (see Table 9)

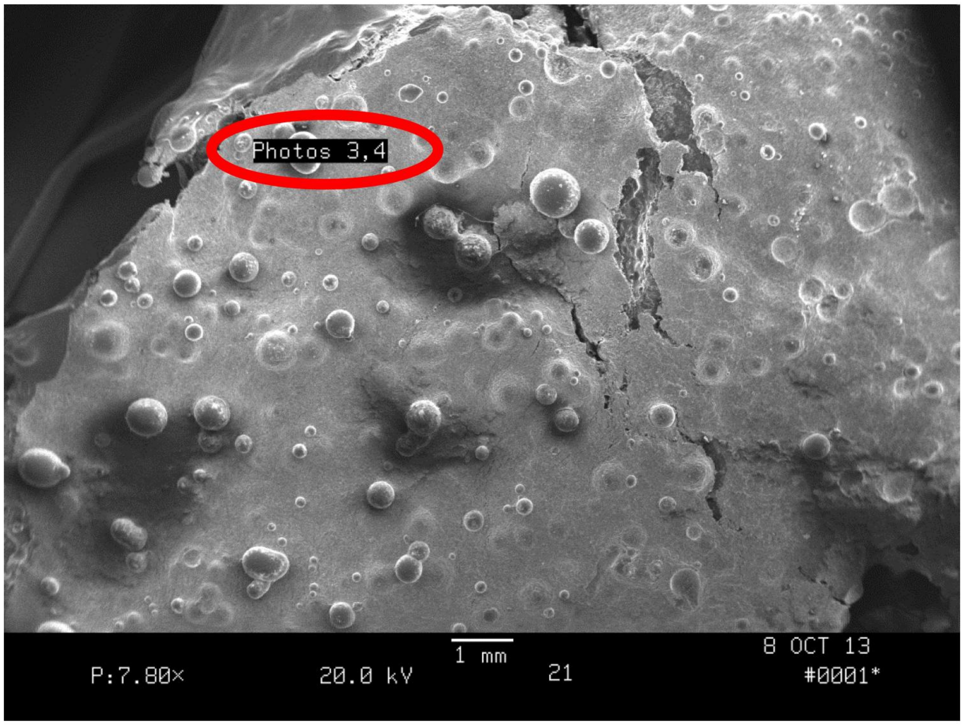


Figure 51 SEM photo of Claremont paint chip showing investigated areas 3 and 4

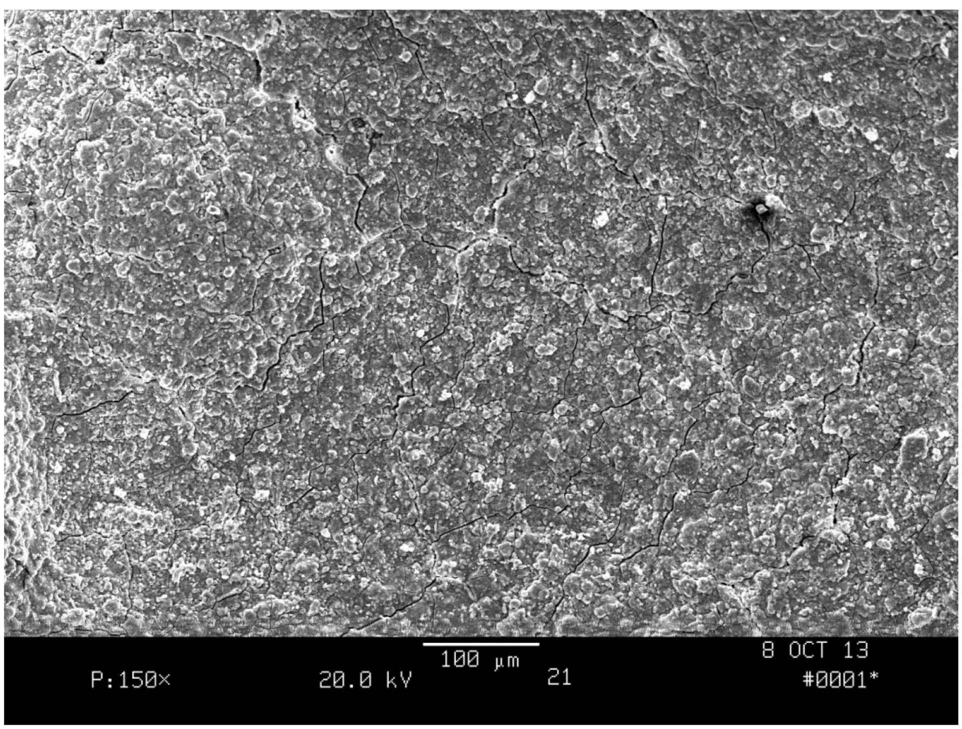


Figure 52 SEM photo (150X) of Claremont paint chip (see Figure 51 for location, Photo 3)

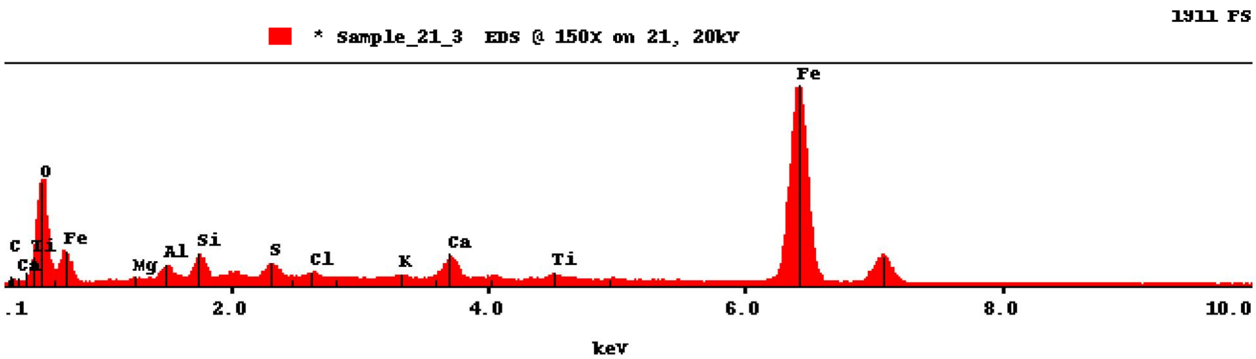


Figure 53 Claremont paint chip elemental spectrum for area shown in Figure 52 (see Table 10)

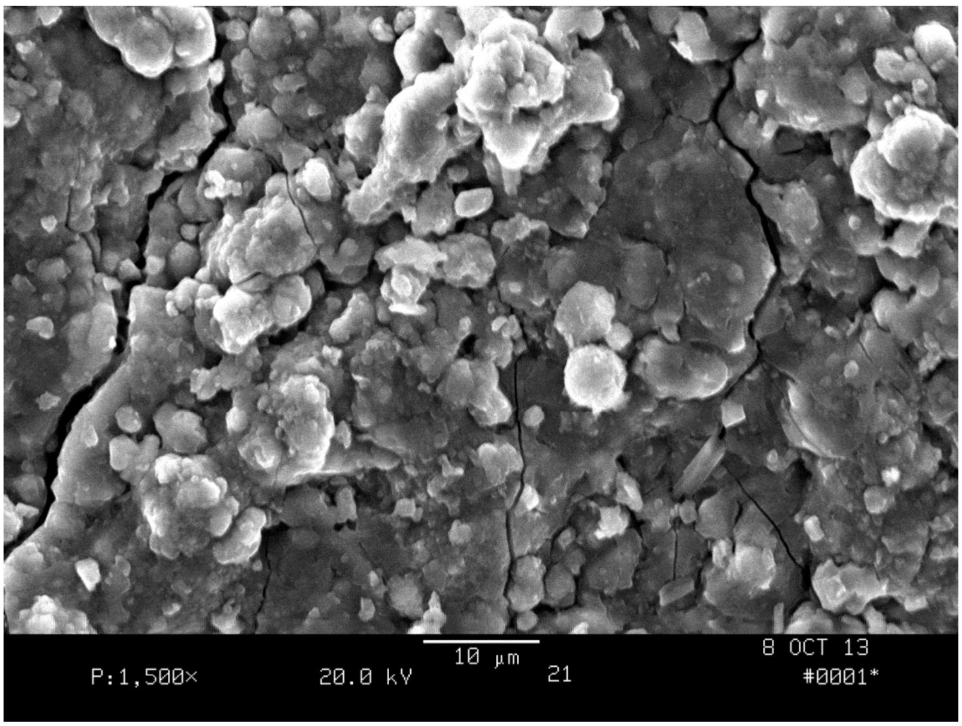


Figure 54 SEM photo (1500X) of Claremont paint chip (see Figure 51 for location, Photo 4)

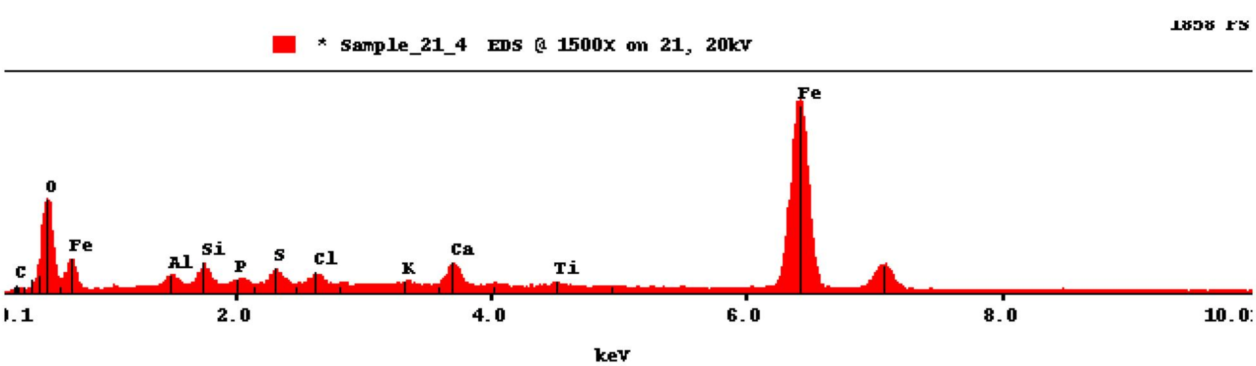


Figure 55 Claremont paint chip elemental spectrum for area shown in Figure 54 (see Table 11)

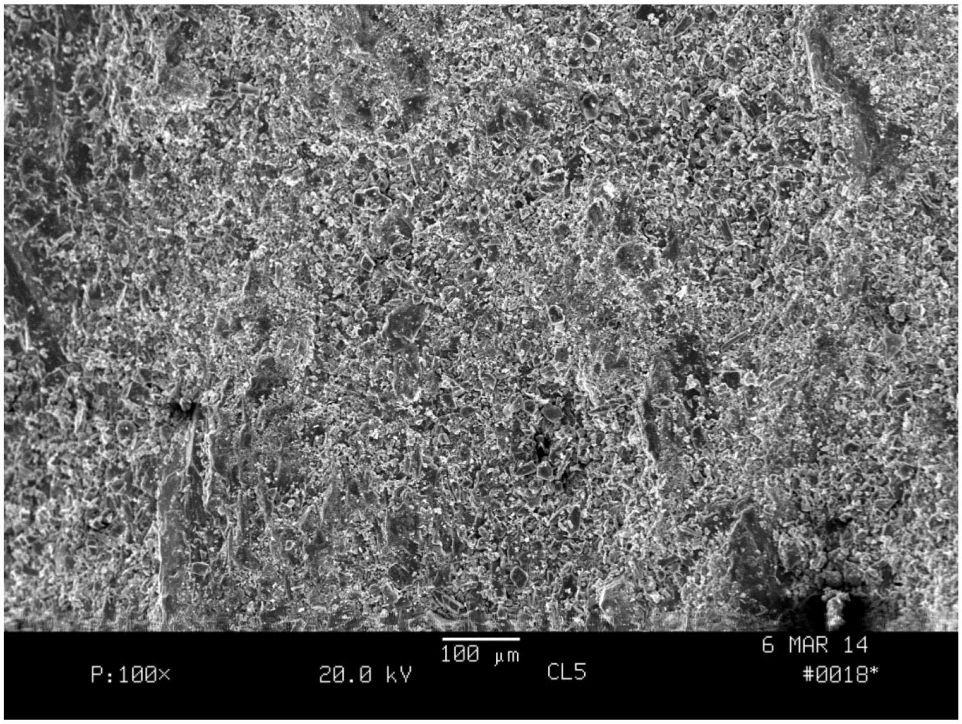


Figure 56 SEM photo (100X) of Claremont paint chip

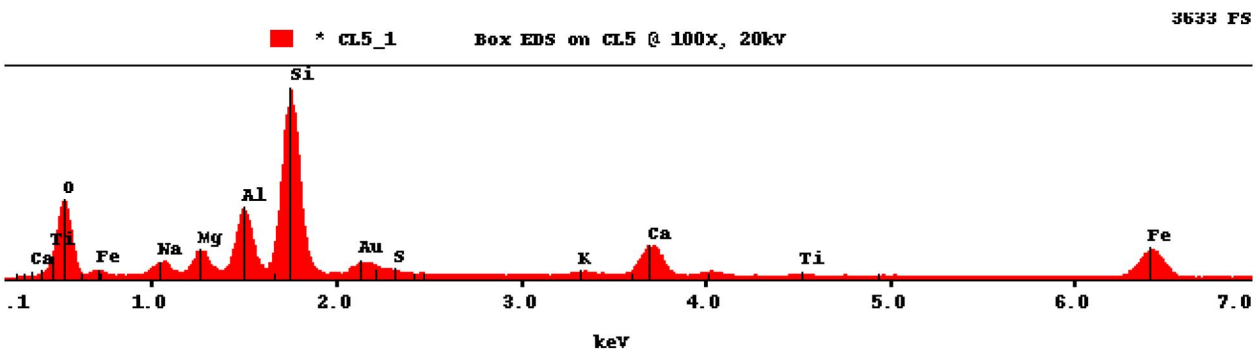


Figure 57 Claremont paint chip elemental spectrum for area shown in Figure 56 (see Table 12)

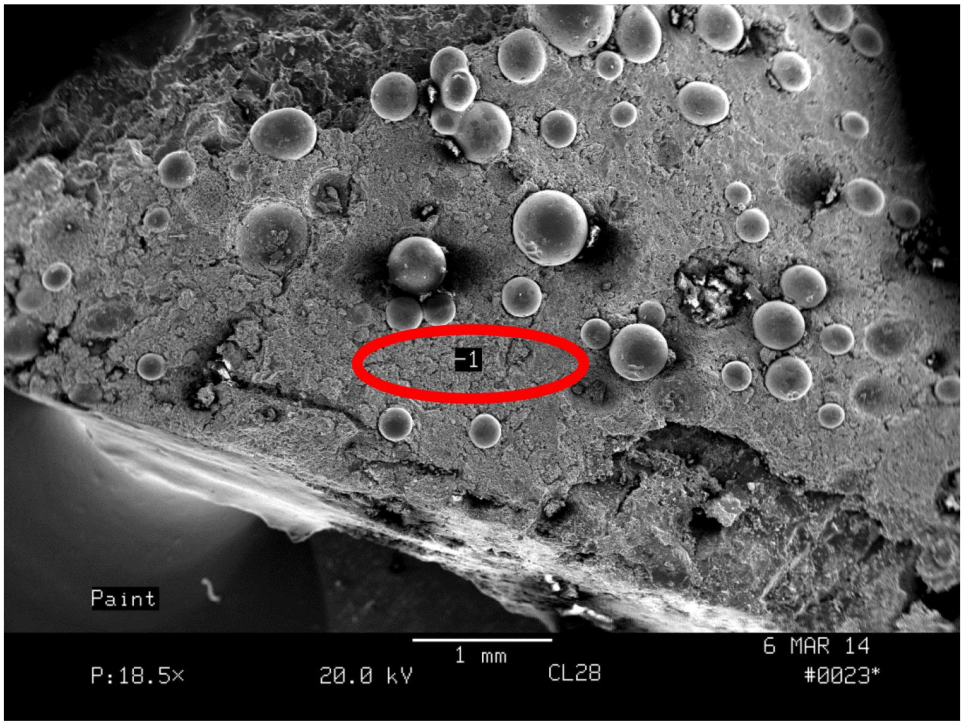


Figure 58 SEM photo of Claremont paint chip showing position 1

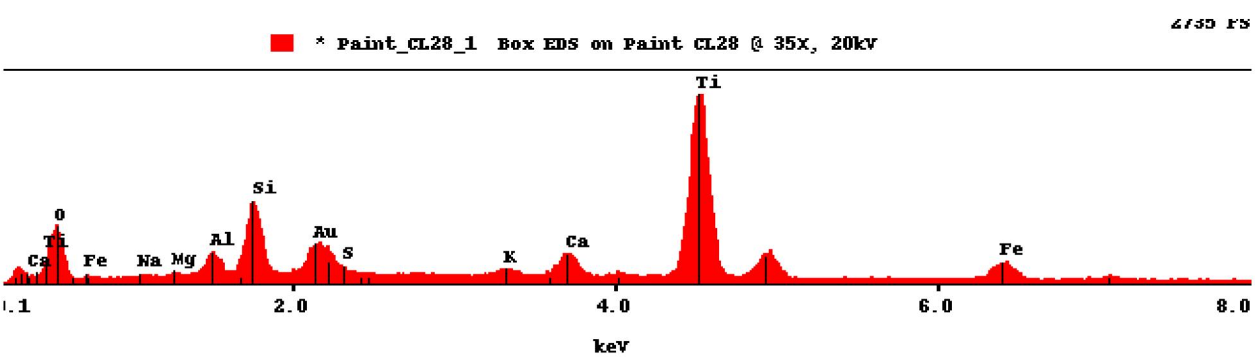


Figure 59 Claremont paint chip elemental spectrum for area shown in Figure 58 (see Table 13)

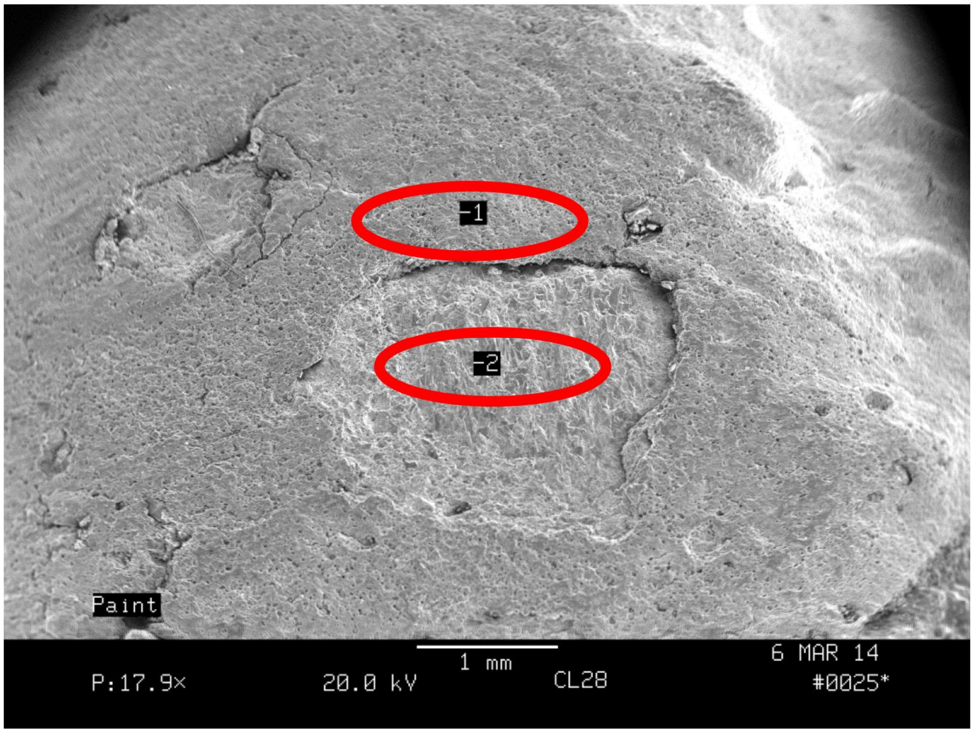


Figure 60 SEM photo of Claremont paint chip showing position 1 and 2

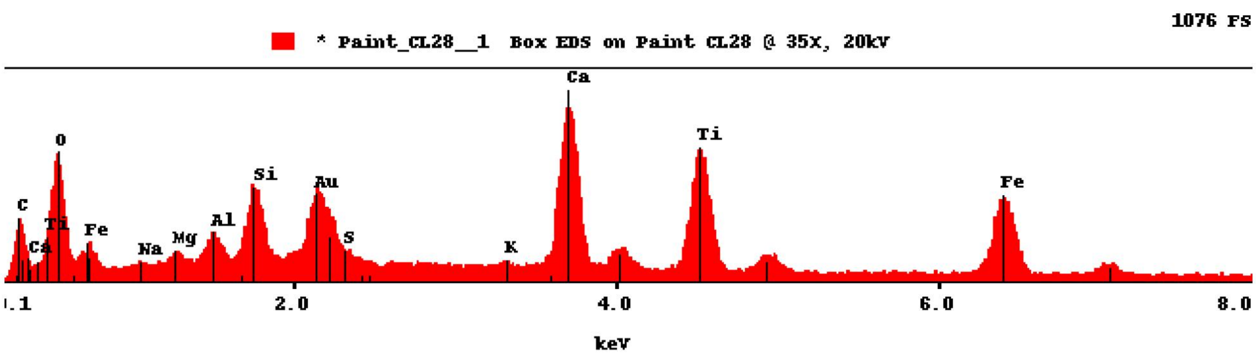


Figure 61 Claremont paint chip elemental spectrum for position 1 shown in Figure 60 (see Table 14)

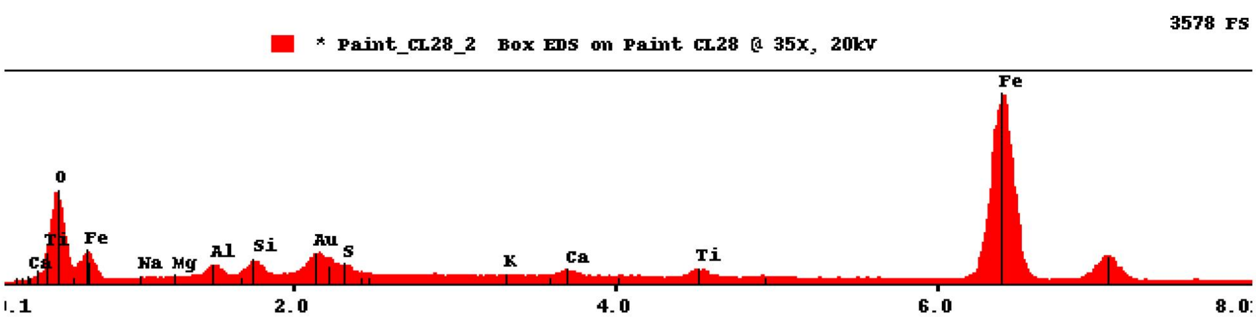


Figure 62 Claremont paint chip elemental spectrum for area 2 shown in Figure 60 (see Table 15)

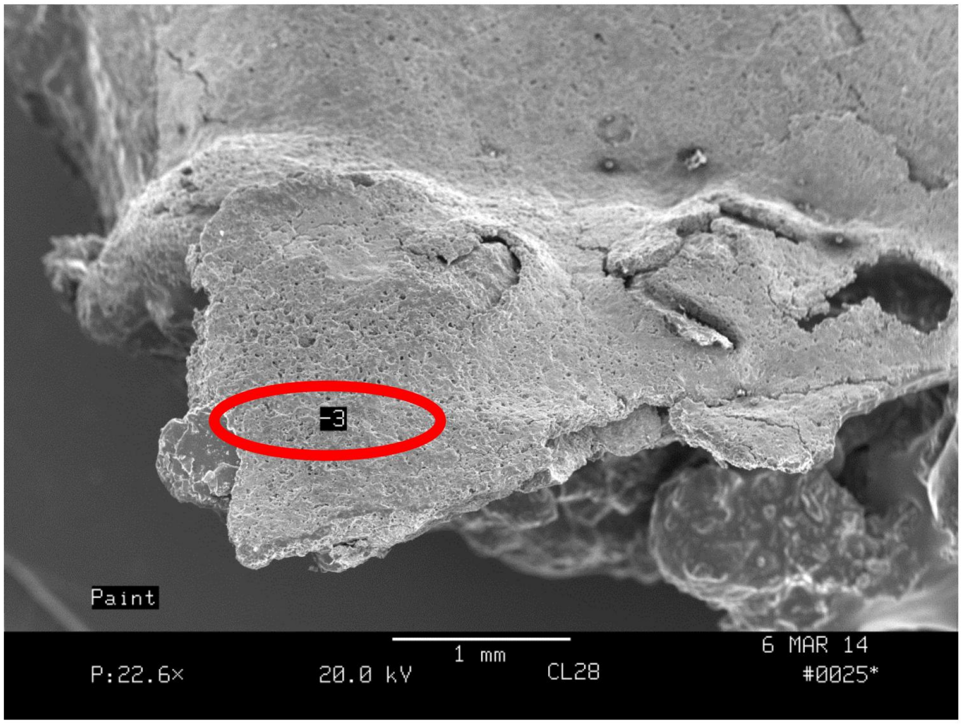


Figure 63 SEM photo of Claremont paint chip showing position 3

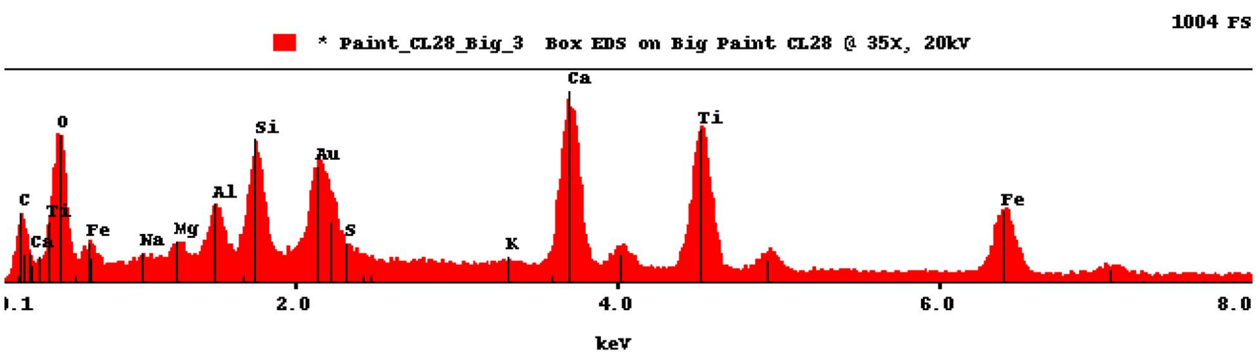


Figure 64 Claremont paint chip elemental spectrum for area 3 shown in Figure 63 (see Table 16)

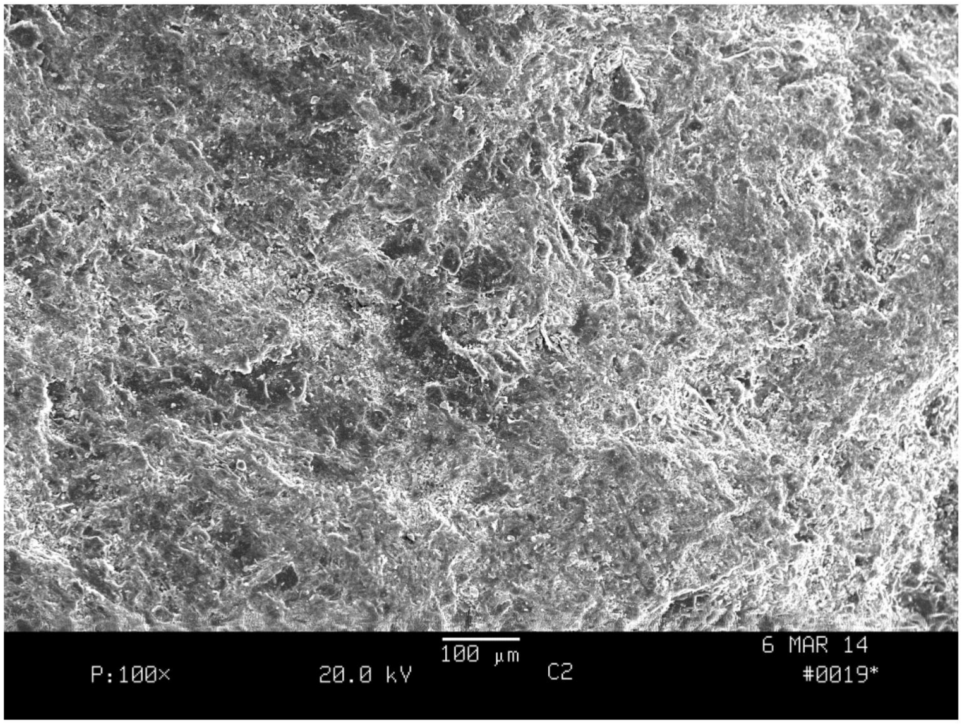


Figure 65 SEM photo of Concord paint chip

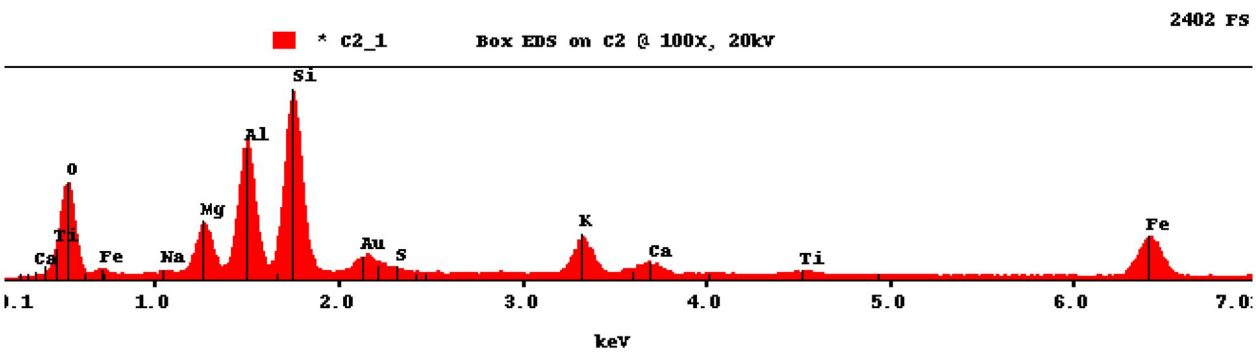


Figure 66 Concord paint chip elemental spectrum for area shown in Figure 65 (see Table 17)

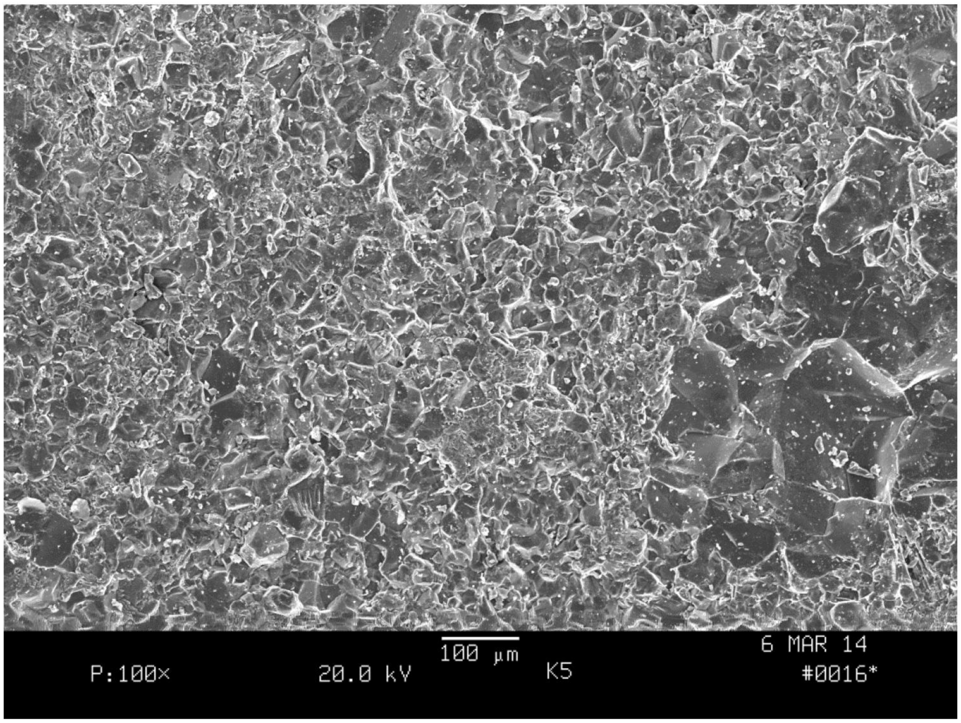


Figure 67 SEM photo of Keene paint chip

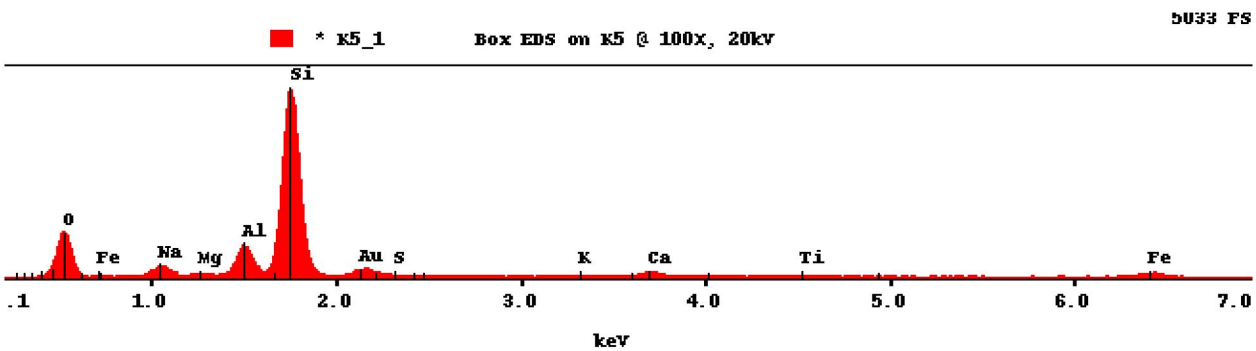


Figure 68 Keene paint chip elemental spectrum for area shown in Figure 67 (see Table 18)

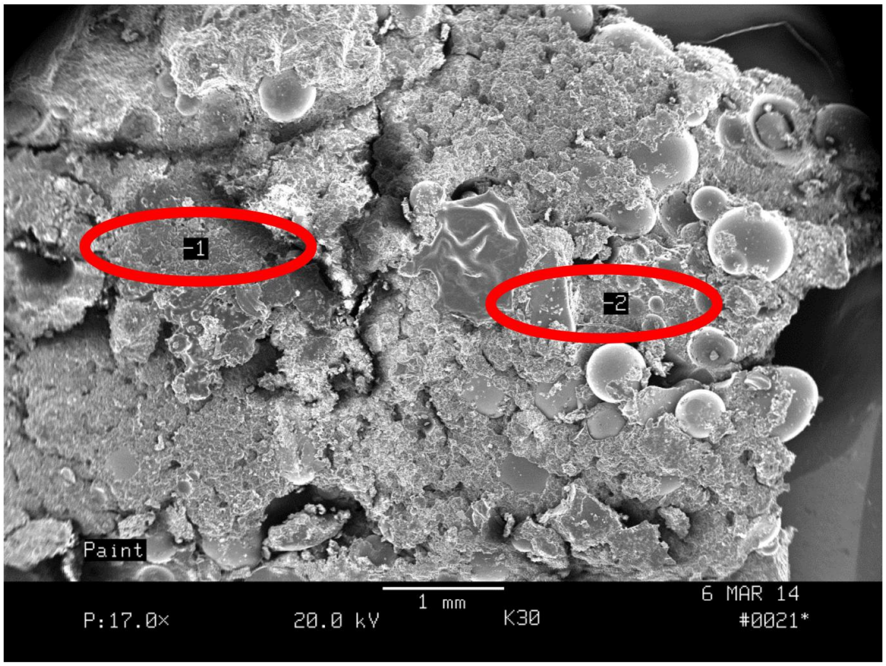
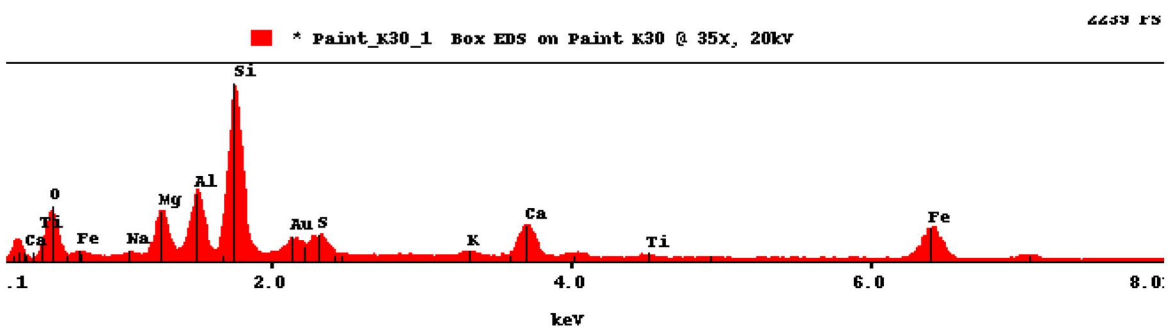


Figure 69 SEM photo of Keene paint chip showing positions 1 and 2

Position 1



Position 2

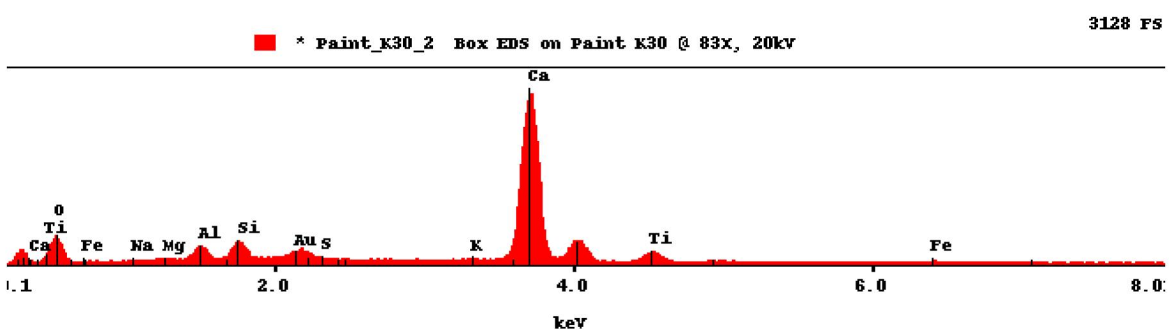


Figure 70 Keene paint chip elemental spectrum for areas 1 and 2 shown in Figure 69 (see Tables 19 and 20)

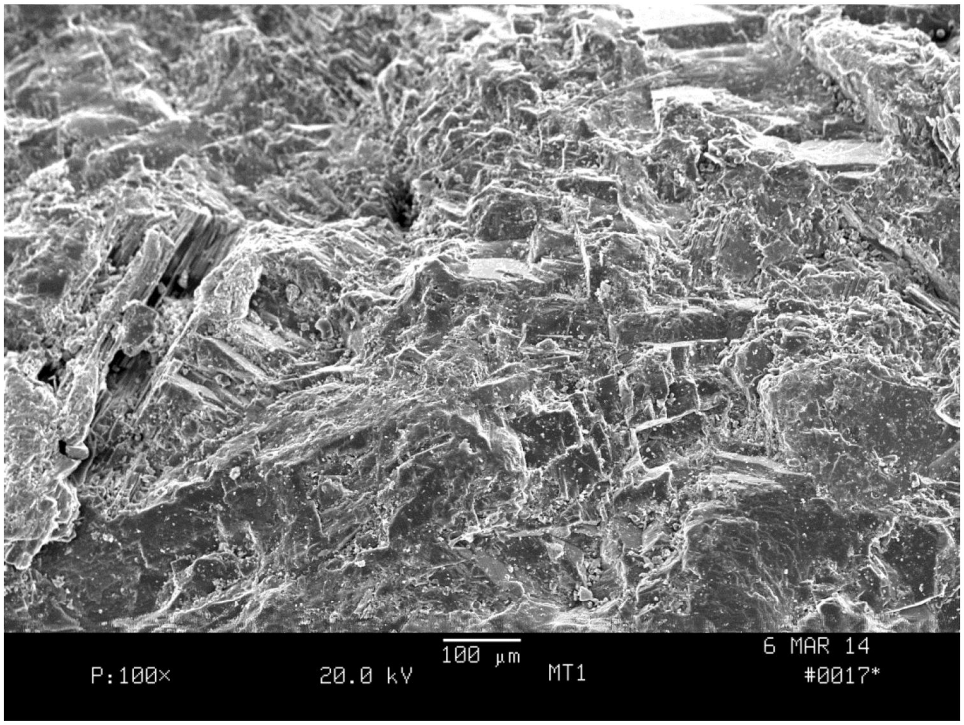


Figure 71 SEM photo of Whitefield paint chip (100X)

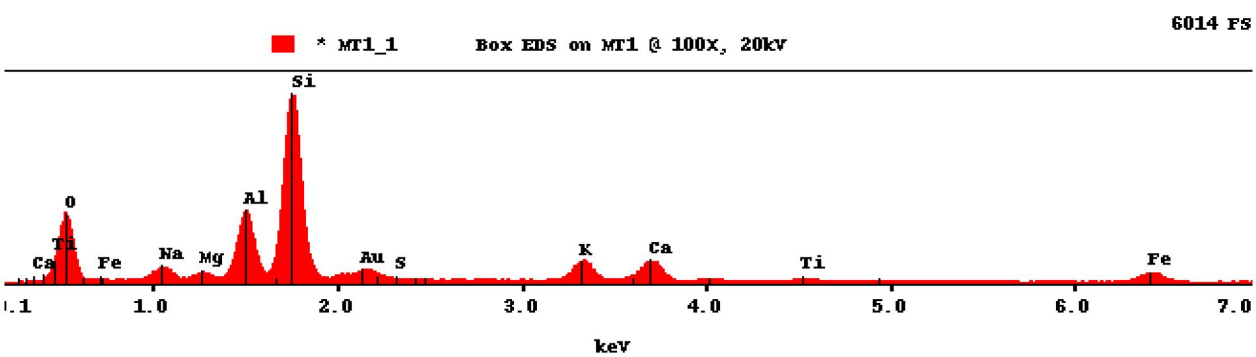


Figure 72 Whitefield paint chip elemental spectrum for area shown in Figure 71 (see Table 21)

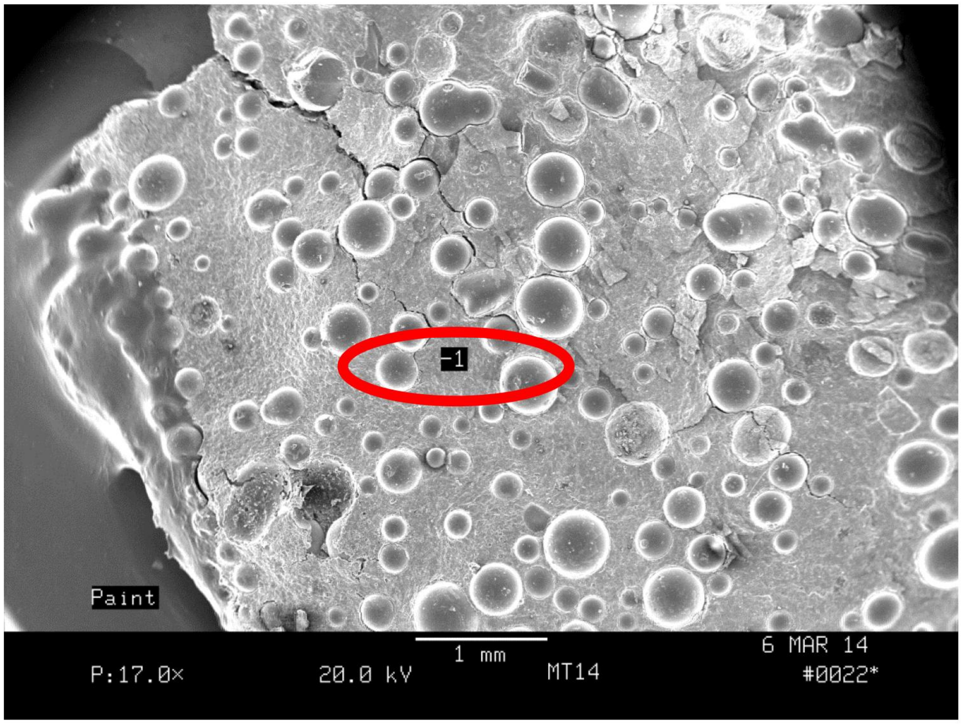


Figure 73 SEM photo of Whitefield paint chip showing location 1

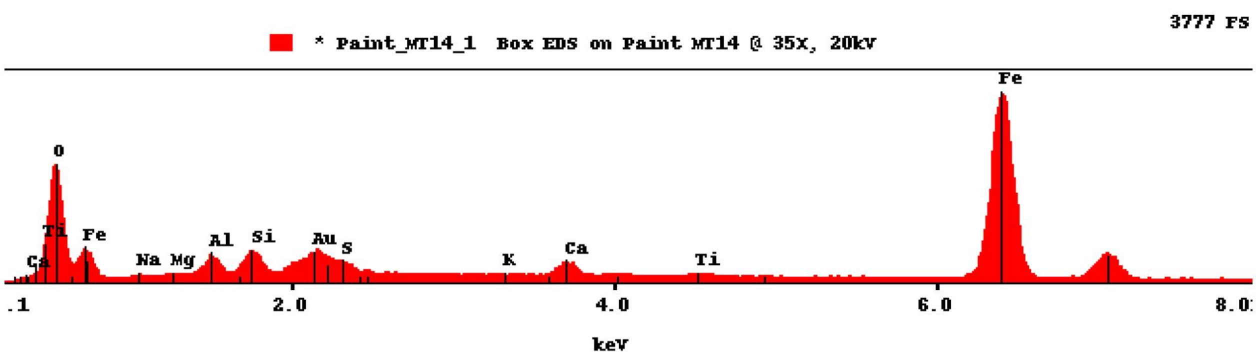


Figure 74 Whitefield paint chip elemental spectrum for area shown in Figure 73 (see Table 22)

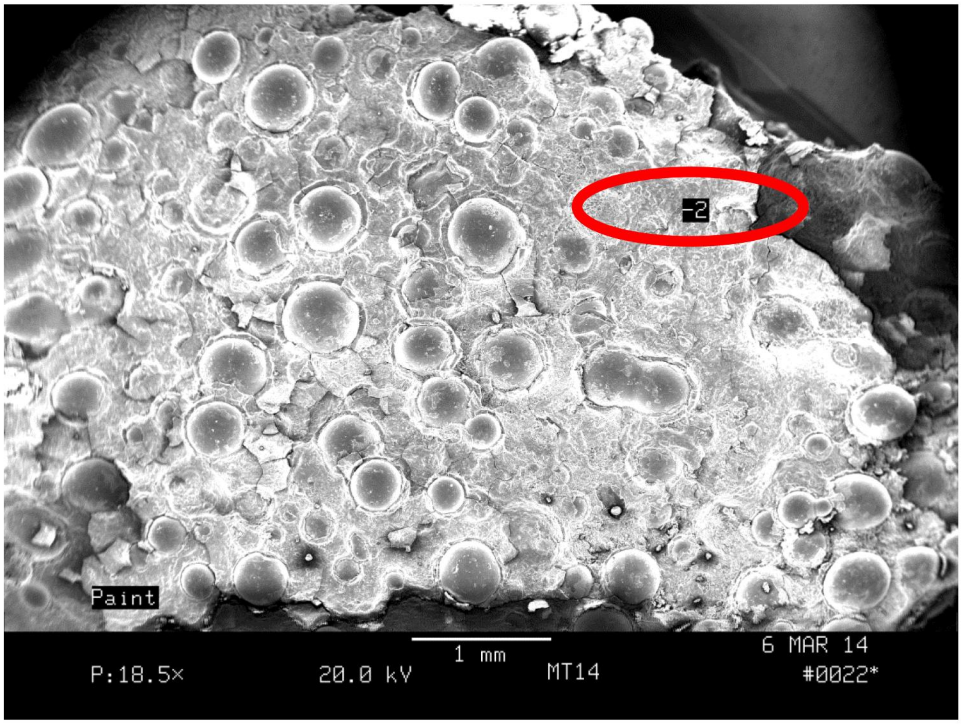


Figure 75 SEM photo of Whitefield paint chip showing location 2

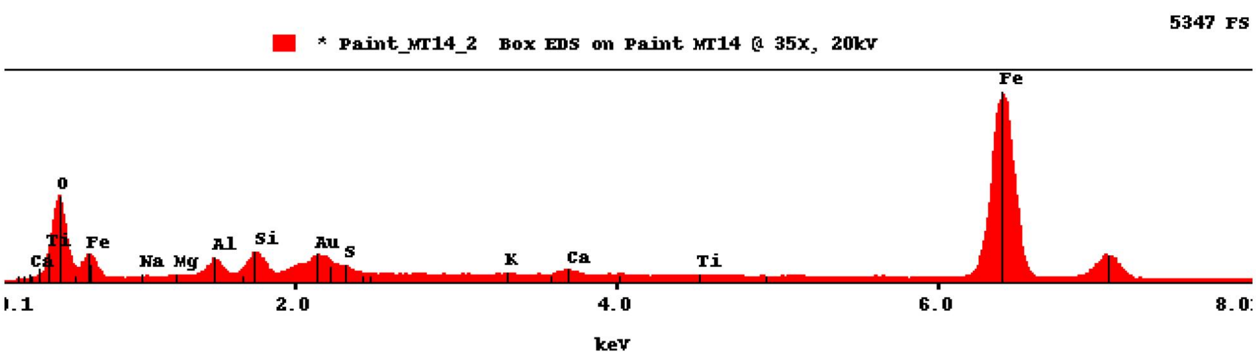


Figure 76 Whitefield paint chip elemental spectrum for position 2 shown in Figure 75 (see Table 23)

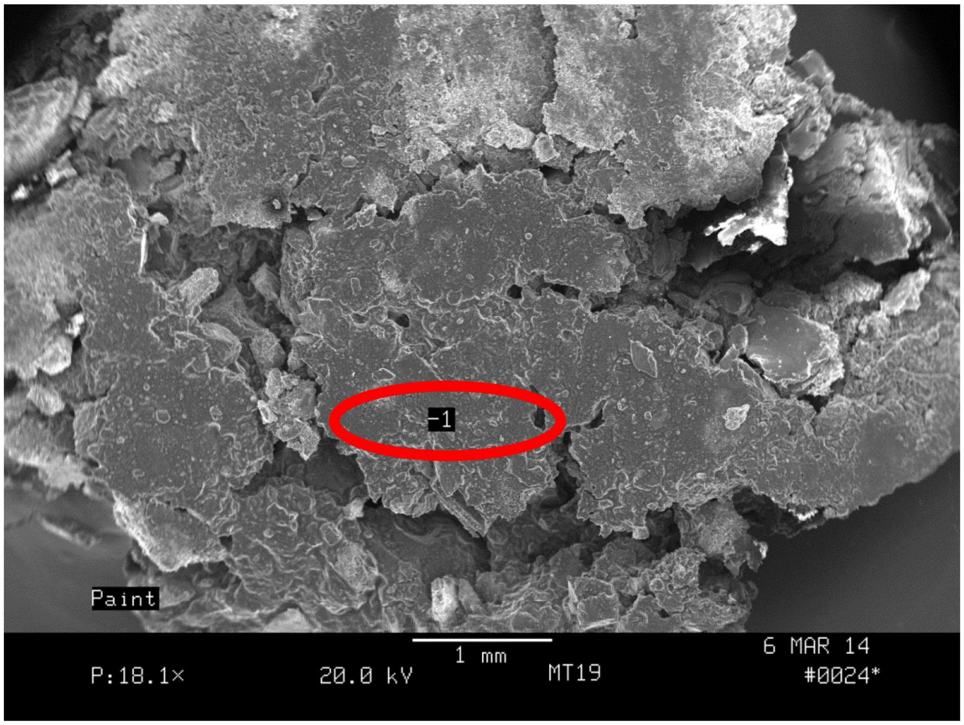


Figure 77 SEM photo of Whitefield paint chip showing position 1

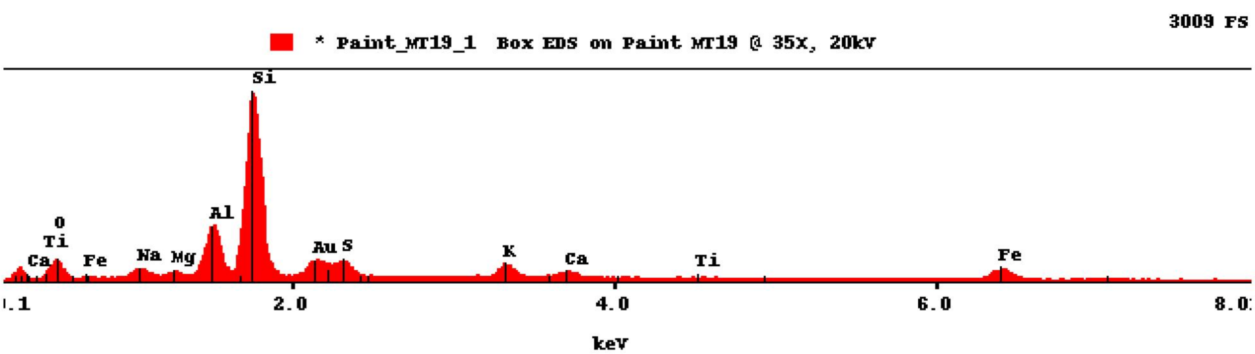


Figure 78 Whitefield paint chip elemental spectrum for position 1 shown in Figure 77 (see Table 24)

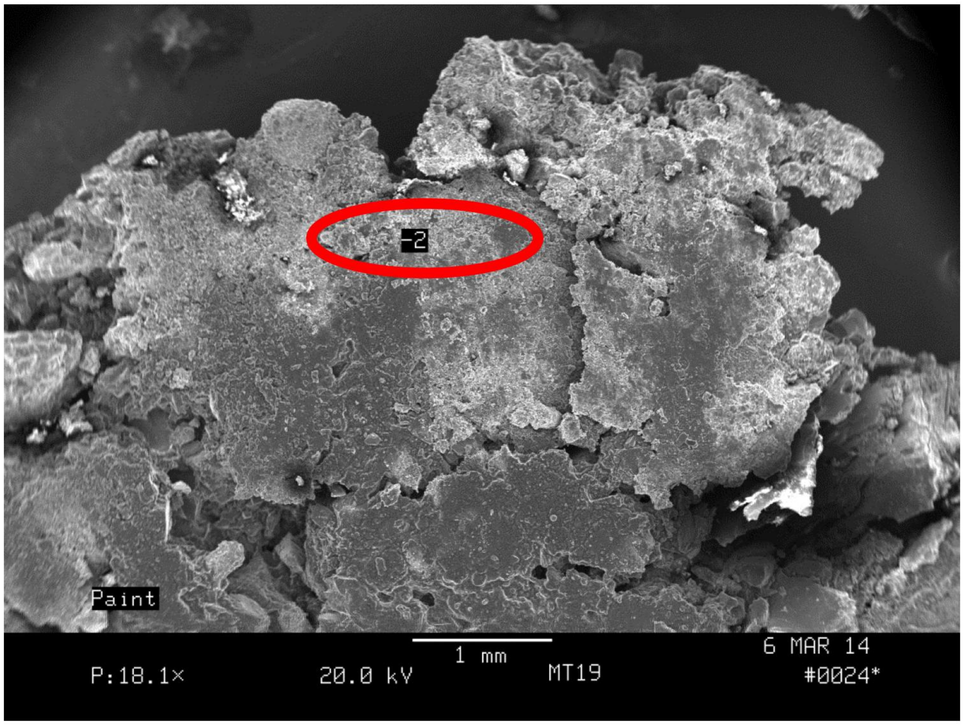


Figure 79 SEM photo of Whitefield paint chip showing position 2

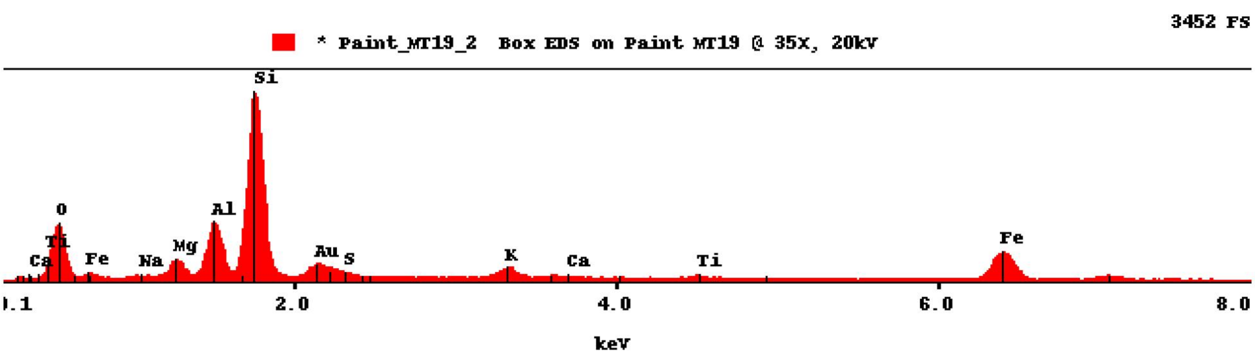


Figure 80 Whitefield paint chip elemental spectrum for position 2 shown in Figure 79 (see Table 25)

Figure 81 Concord magnetic aggregates

Figure 82 Claremont magnetic aggregates

Figure 83 Keene magnetic aggregates

Figure 84 Laconia magnetic aggregates

Figure 85 Whitefield magnetic aggregates

Figure 86 Claremont magnetic aggregate epoxy disk side A after polished in ethanol alcohol

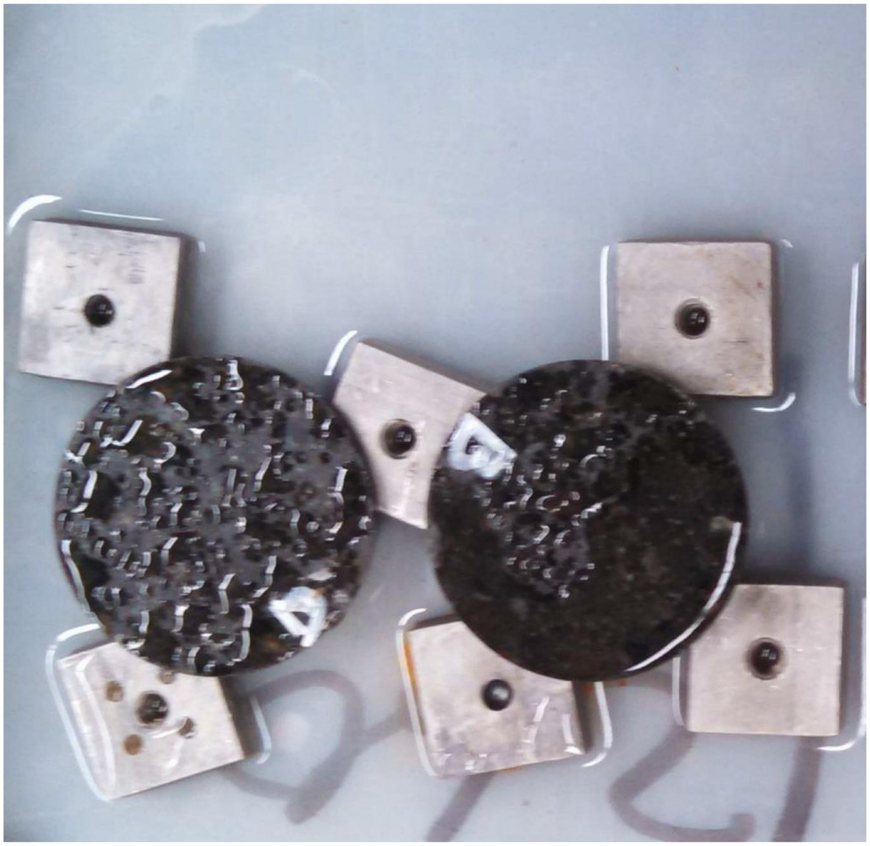


Figure 87 Claremont epoxy disks A/B and C/D stored over water

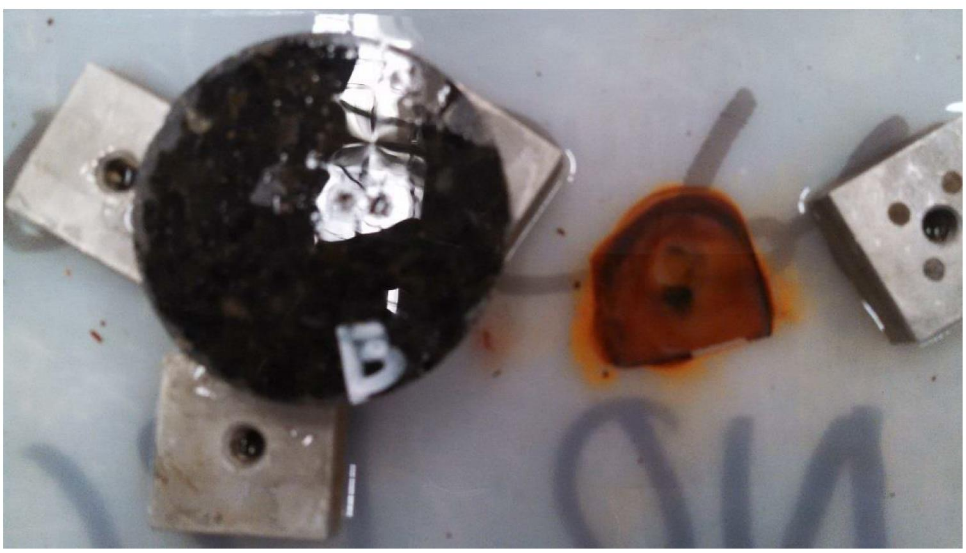
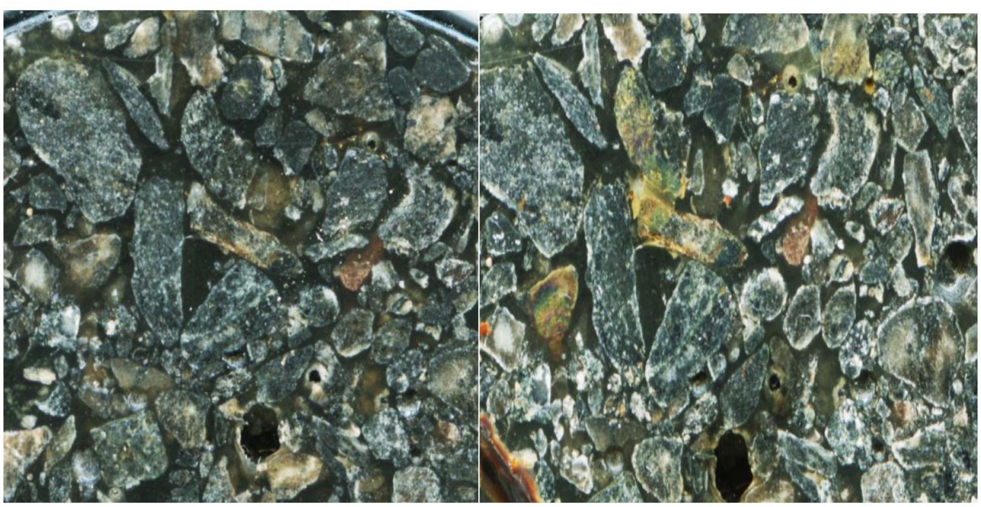


Figure 88 Claremont epoxy disk B/A after 3 months in moist air held at 100 ^oF (note: rust stain on bottom of plastic container)

Figure 89 Claremont magnetic aggregate epoxy disk side A after soaked over water at 100 ^{o}F for 3 months



Before Soaked After Soaked

Figure 90 Claremont magnetic aggregate epoxy disk side A close up before and after soaked over water at 100 ^{o}F for 3 months

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APPENDIX D2 - SEM and EDS Table Results

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Table 1 Laconia paint chip SEM elemental data for area shown in Figure 32

Sample /xd1/window1/#1,/Sample_8_1.spt
Accelerating Voltage: 20.00 keV
Takeoff Angle: 30.00 degrees
Library for system standards: /imix/quant/efficiency/default.dir

Elm	Rel. K	ZAF	Norm wt%	Prec.	Atomic %	Standard	Intensity
Fe	0.3281	1.1099	36.42	1.70	19.02	(S)Fe_K	10458
Na	0.0050	4.8975	2.46	0.65	3.12	(S)Na_K	509
Mg	0.0016	3.1062	0.51	0.31	0.62	(S)Mg_K	201
Al	0.0128	2.2549	2.88	0.48	3.11	(S)Al_K	1228
Si	0.0834	1.7633	14.70	0.80	15.26	(S)Si_K	8093
S	0.0046	1.4441	0.66	0.23	0.60	(S)S_K	460
K	0.0041	1.1230	0.46	0.19	0.34	(S)K_K	375
Ca	0.0285	1.0452	2.98	0.34	2.16	(S)Ca_K	2207
Ti	0.1150	1.0866	12.50	0.76	7.61	(S)Ti_K	6488
O	0.0674	3.9215	26.43	1.93	48.15	(S)O_K	4385
Total			100.00		99.99		

Table 2 Laconia paint chip SEM elemental data for area shown in Figure 34

Sample /xd1/window1/#1,/Sample_8_2.spt
Accelerating Voltage: 20.00 keV
Takeoff Angle: 30.00 degrees
Library for system standards: /imix/quant/efficiency/default.dir

Elm	Rel. K	ZAF	Norm wt%	Prec.	Atomic %	Standard	Intensity
Fe	0.0549	1.1721	6.44	0.89	3.05	(S)Fe_K	1516
Na	0.0000	4.2094	0.01	0.07	0.01	(S)Na_K	14 ?
Mg	0.0013	2.6491	0.35	0.52	0.39	(S)Mg_K	83 ?
Al	0.0136	1.9810	2.70	0.44	2.65	(S)Al_K	1371
Si	0.0390	1.5888	6.20	0.56	5.86	(S)Si_K	3426
S	0.0075	1.2663	0.95	0.26	0.79	(S)S_K	686
K	0.0062	1.0341	0.64	0.22	0.43	(S)K_K	507
Ca	0.0384	0.9643	3.70	0.37	2.45	(S)Ca_K	2759
Ti	0.3813	1.1059	42.17	1.41	23.33	(S)Ti_K	20140
O	0.0450	8.1911	36.84	3.63	61.04	(S)O_K	2553
Total			100.00		100.00		

Table 3 Laconia paint chip SEM elemental data for area shown in Figure 35

Sample /xd1/window1/#1,/Sample_8_3.spt
Accelerating Voltage: 20.00 keV
Takeoff Angle: 30.00 degrees
Library for system standards: /imix/quant/efficiency/default.dir

Elm	Rel. K	ZAF	Norm wt%	Prec.	Atomic %	Standard	Intensity	
Fe	0.7078	1.0456	74.01	2.09	50.27	(S)Fe_K	27776	
Na	0.0001	6.6374	0.08	0.36	0.13	(S)Na_K	20	?
Mg	0.0008	3.9032	0.31	0.69	0.47	(S)Mg_K	48	?
Al	0.0096	2.7187	2.61	0.45	3.67	(S)Al_K	1132	
Si	0.0139	2.0224	2.81	0.39	3.80	(S)Si_K	1694	
S	0.0082	1.3957	1.15	0.22	1.36	(S)S_K	1087	
K	0.0035	1.0925	0.38	0.20	0.37	(S)K_K	318	
Ca	0.0107	1.0103	1.08	0.24	1.03	(S)Ca_K	919	
Ti	0.0177	0.9883	1.75	0.32	1.39	(S)Ti_K	1165	
O	0.0729	2.1713	15.82	0.94	37.53	(S)O_K	6356	
Total			100.00		100.02			

Table 4 Laconia paint chip SEM elemental data for area 1shown in Figure 41

Sample /xd1/window1/#1,/Paint_L1_1.spt
Accelerating Voltage: 20.00 keV
Takeoff Angle: 30.00 degrees
Library for system standards: /imix/quant/efficiency/default.dir

Elm	Rel. K	ZAF	Norm wt%	Prec.	Atomic %	Standard	Intensity	
Ti	0.0068	1.0527	0.72	0.24	0.44	(S)Ti_K	526	
Ca	0.0074	1.0601	0.78	0.23	0.56	(S)Ca_K	616	
Si	0.0160	2.1522	3.44	0.55	3.54	(S)Si_K	1514	
Al	0.0856	2.2870	19.58	0.91	20.98	(S)Al_K	10982	
S	0.0058	1.4787	0.86	0.12	0.78	(S)S_K	1797	
Fe	0.4366	1.0815	47.22	1.72	24.44	(S)Fe_K	16988	
K	0.0012	1.1453	0.14	0.17	0.10	(S)K_K	125	?
Na	0.0003	5.2145	0.17	0.72	0.22	(S)Na_K	28	?
Mg	0.0000	3.1678	0.00	0.00	0.00	(S)Mg_K	59	?
O	0.1180	2.2967	27.09	1.33	48.95	(S)O_K	9603	
Total			100.00		100.01			

Table 5 Laconia paint chip SEM elemental data for area 2 shown in Figure 41

Sample /xd1/window1/#1,/Paint_L1_2.spt
Accelerating Voltage: 20.00 keV
Takeoff Angle: 30.00 degrees
Library for system standards: /imix/quant/efficiency/default.dir

Elm	Rel. K	ZAF	Norm wt%	Prec.	Atomic %	Standard	Intensity
Ti	0.0448	1.0254	4.59	0.48	3.17	(S)Ti_K	2622
Ca	0.0094	1.0300	0.97	0.25	0.81	(S)Ca_K	726
Si	0.0295	2.0135	5.94	0.58	6.98	(S)Si_K	3057
Al	0.0309	2.5105	7.75	0.71	9.49	(S)Al_K	3311
S	0.0010	1.4364	0.15	0.03	0.16	(S)S_K	903
Fe	0.5446	1.0691	58.22	2.10	34.46	(S)Fe_K	17388
K	0.0046	1.1113	0.51	0.23	0.43	(S)K_K	363
Na	0.0009	5.8927	0.51	1.42	0.73	(S)Na_K	38 ?
Mg	0.0014	3.5354	0.51	0.97	0.69	(S)Mg_K	67 ?
O	0.0810	2.5731	20.85	1.36	43.06	(S)O_K	5595
Total			100.00		99.98		

Table 6 Laconia paint chip SEM elemental data for area 3 shown in Figure 44

Sample /xd1/window1/#1,/Paint_L1_3.spt
Accelerating Voltage: 20.00 keV
Takeoff Angle: 30.00 degrees
Library for system standards: /imix/quant/efficiency/default.dir

Elm	Rel. K	ZAF	Norm wt%	Prec.	Atomic %	Standard	Intensity
Ti	0.0879	1.0609	9.33	0.68	5.79	(S)Ti_K	4702
Ca	0.0146	1.0393	1.52	0.29	1.13	(S)Ca_K	1004
Si	0.0460	1.9298	8.87	0.73	9.40	(S)Si_K	3984
Al	0.0380	2.3201	8.82	0.76	9.72	(S)Al_K	3644
S	0.0000	1.4441	0.00	0.00	0.00	(S)S_K	570
Fe	0.3986	1.0942	43.62	1.90	23.25	(S)Fe_K	11974
K	0.0049	1.1185	0.55	0.26	0.42	(S)K_K	332
Na	0.0002	5.2757	0.13	0.70	0.17	(S)Na_K	19 ?
Mg	0.0020	3.2029	0.64	0.67	0.78	(S)Mg_K	125 ?
O	0.0814	3.2580	26.52	1.74	49.32	(S)O_K	5445
Total			100.00		99.98		

Table 7 Laconia paint chip SEM elemental data for area 2 and 3 shown in Figure 44

Sample /xd1/window1/#1,/L2+3_1.spt
Accelerating Voltage: 20.00 keV
Takeoff Angle: 30.00 degrees
Library for system standards: /imix/quant/efficiency/default.dir

Elm	Rel. K	ZAF	Norm wt%	Prec.	Atomic %	Standard	Intensity
Ti	0.0223	1.1802	2.63	0.41	1.35	(S)Ti_K	1357
Ca	0.0292	1.1522	3.37	0.35	2.06	(S)Ca_K	2550
Si	0.1705	1.6940	28.88	1.00	25.16	(S)Si_K	19523
Al	0.0673	1.7757	11.95	0.66	10.84	(S)Al_K	8307
S	0.0000	1.6244	0.00	0.00	0.00	(S)S_K	443
Fe	0.1238	1.1385	14.09	1.03	6.18	(S)Fe_K	4514
K	0.0267	1.2157	3.24	0.34	2.03	(S)K_K	2542
Na	0.0076	3.1516	2.39	0.48	2.55	(S)Na_K	921
Mg	0.0117	2.1895	2.56	0.45	2.58	(S)Mg_K	1221
O	0.0798	3.8732	30.89	1.87	47.26	(S)O_K	6409
Total			100.00		100.01		

Table 8 Claremont paint chip SEM elemental data for area shown in Figure 48

Sample /xd1/window1/#2,/Sample_21_1.spt
Accelerating Voltage: 20.00 keV
Takeoff Angle: 30.00 degrees
Library for system standards: /imix/quant/efficiency/default.dir

Elm	Rel. K	ZAF	Norm wt%	Prec.	Atomic %	Standard	Intensity	
Fe	0.7801	1.0351	80.75	2.41	59.33	(S)Fe_K	25055	
Na	0.0000	6.8877	0.00	0.00	0.00	(S)Na_K	11	?
Mg	0.0004	4.0342	0.17	0.34	0.30	(S)Mg_K	45	?
Al	0.0027	2.7920	0.74	0.25	1.13	(S)Al_K	399	
Si	0.0076	2.0227	1.54	0.37	2.26	(S)Si_K	691	
S	0.0145	1.3774	2.00	0.29	2.56	(S)S_K	1507	
Ca	0.0169	1.0007	1.69	0.27	1.73	(S)Ca_K	1310	
Ti	0.0053	0.9750	0.52	0.20	0.44	(S)Ti_K	403	
O	0.0609	2.0668	12.59	0.92	32.30	(S)O_K	4313	
Total			100.00		100.05			

Table 9 Claremont paint chip SEM elemental data for area shown in Figure 50

Sample /xd1/window1/#1,/Sample_21_2.spt
Accelerating Voltage: 20.00 keV
Takeoff Angle: 30.00 degrees
Library for system standards: /imix/quant/efficiency/default.dir

Elm	Rel. K	ZAF	Norm wt%	Prec.	Atomic %	Standard	Intensity	
Fe	0.7271	1.0439	75.90	2.06	52.18	(S)Fe_K	30324	
Na	0.0003	6.7666	0.18	0.31	0.29	(S)Na_K	51	?
Mg	0.0003	3.9735	0.10	0.51	0.16	(S)Mg_K	20	?
Al	0.0045	2.7528	1.24	0.42	1.77	(S)Al_K	462	
Si	0.0073	2.0108	1.47	0.33	2.01	(S)Si_K	855	
S	0.0158	1.3755	2.17	0.27	2.60	(S)S_K	2102	
Ca	0.0229	1.0070	2.31	0.28	2.22	(S)Ca_K	2118	
Ti	0.0072	0.9892	0.71	0.19	0.56	(S)Ti_K	668	
O	0.0743	2.1436	15.92	0.92	38.20	(S)O_K	6675	
Total			100.00		99.99			

Table 10 Claremont paint chip SEM elemental data for area shown in Figure 53

Sample /xd1/window1/#1,/Sample_21_3.spt
Accelerating Voltage: 20.00 keV
Takeoff Angle: 30.00 degrees
Library for system standards: /imix/quant/efficiency/default.dir

Elm	Rel. K	ZAF	Norm wt%	Prec.	Atomic %	Standard	Intensity	
K	0.0030	1.0975	0.33	0.18	0.31	(S)K_K	260	
Mg	0.0014	3.8361	0.53	0.63	0.78	(S)Mg_K	92	?
Al	0.0085	2.6858	2.28	0.47	3.05	(S)Al_K	861	
Si	0.0149	1.9968	2.97	0.43	3.82	(S)Si_K	1505	
S	0.0088	1.3899	1.23	0.25	1.38	(S)S_K	974	
Ca	0.0251	1.0186	2.56	0.33	2.30	(S)Ca_K	1823	
Ti	0.0092	1.0067	0.93	0.27	0.71	(S)Ti_K	547	
Fe	0.6651	1.0535	70.07	2.28	45.26	(S)Fe_K	21055	
Cl	0.0042	1.2976	0.54	0.28	0.56	(S)Cl_K	300	
O	0.0823	2.2564	18.56	1.16	41.85	(S)O_K	5837	
Total			100.00		100.02			

Table 11 Claremont paint chip SEM elemental data for area shown in Figure 55

Sample /xd1/window1/#1,/Sample_21_4.spt
Accelerating Voltage: 20.00 keV
Takeoff Angle: 30.00 degrees
Library for system standards: /imix/quant/efficiency/default.dir

Elm	Rel. K	ZAF	Norm wt%	Prec.	Atomic %	Standard	Intensity
Fe	0.6683	1.0530	70.37	2.36	46.06	(S)Fe_K	19890
Al	0.0072	2.6687	1.92	0.44	2.60	(S)Al_K	724
Si	0.0124	1.9777	2.46	0.42	3.20	(S)Si_K	1163
P	0.0048	1.6687	0.80	0.36	0.94	(S)P_K	345
S	0.0106	1.3863	1.47	0.28	1.67	(S)S_K	1006
Cl	0.0081	1.2976	1.05	0.24	1.09	(S)Cl_K	801
K	0.0038	1.1004	0.42	0.21	0.39	(S)K_K	294
Ca	0.0284	1.0216	2.90	0.37	2.65	(S)Ca_K	1857
Ti	0.0074	1.0104	0.75	0.29	0.57	(S)Ti_K	376
O	0.0769	2.3222	17.86	1.28	40.83	(S)O_K	4731
Total			100.00		100.00		

Table 12 Claremont paint chip SEM elemental data for area shown in Figure 57

Sample /xd1/window1/#1,/CL5_1.spt
Accelerating Voltage: 20.00 keV
Takeoff Angle: 30.00 degrees
Library for system standards: /imix/quant/efficiency/default.dir

Elm	Rel. K	ZAF	Norm wt%	Prec.	Atomic %	Standard	Intensity
Ti	0.0047	1.1832	0.56	0.25	0.29	(S)Ti_K	345
Ca	0.0478	1.1422	5.46	0.38	3.30	(S)Ca_K	5222
Si	0.1741	1.7061	29.71	0.89	25.66	(S)Si_K	25405
Al	0.0575	1.8402	10.59	0.58	9.52	(S)Al_K	8425
S	0.0013	1.6444	0.22	0.06	0.16	(S)S_K	716
Fe	0.1263	1.1372	14.36	0.94	6.24	(S)Fe_K	5621
K	0.0035	1.2228	0.43	0.14	0.27	(S)K_K	520
Na	0.0123	3.0764	3.78	0.57	3.99	(S)Na_K	1500
Mg	0.0202	2.2036	4.46	0.47	4.45	(S)Mg_K	2774
O	0.0840	3.6232	30.43	1.64	46.14	(S)O_K	8115
Total			100.00		100.02		

Table 13 Claremont paint chip SEM elemental data for area shown in Figure 59

Sample /xd1/window1/#1,/Paint_CL28_1.spt
Accelerating Voltage: 20.00 keV
Takeoff Angle: 30.00 degrees
Library for system standards: /imix/quant/efficiency/default.dir

Elm	Rel. K	ZAF	Norm wt%	Prec.	Atomic %	Standard	Intensity
Ti	0.3446	1.1096	38.24	1.12	20.63	(S)Ti_K	26473
Ca	0.0297	0.9801	2.91	0.30	1.88	(S)Ca_K	2973
Si	0.0563	1.5997	9.01	0.54	8.29	(S)Si_K	7428
Al	0.0175	1.9663	3.45	0.44	3.31	(S)Al_K	2133
S	0.0000	1.3081	0.00	0.00	0.00	(S)S_K	734
Fe	0.0582	1.1692	6.80	0.71	3.15	(S)Fe_K	2616
K	0.0066	1.0516	0.69	0.17	0.46	(S)K_K	880
Na	0.0006	4.1059	0.26	1.11	0.29	(S)Na_K	32 ?
Mg	0.0028	2.6049	0.73	0.46	0.78	(S)Mg_K	253
O	0.0504	7.5169	37.91	2.81	61.23	(S)O_K	4445
Total			100.00		100.02		

Table 14 Claremont paint chip SEM elemental data for area shown in Figure 61

Sample /xd1/window1/#1,/Paint_CL28__1.spt
Accelerating Voltage: 20.00 keV
Takeoff Angle: 30.00 degrees
Library for system standards: /imix/quant/efficiency/default.dir

Elm	Rel. K	ZAF	Norm wt%	Prec.	Atomic %	Standard	Intensity
C	0.0570	3.5308	20.13	2.45	34.50	(S)C_K	1656
Ca	0.1068	1.0256	10.95	0.59	5.63	(S)Ca_K	8439
Si	0.0262	1.5967	4.19	0.43	3.07	(S)Si_K	2927
Al	0.0091	2.0093	1.83	0.37	1.40	(S)Al_K	1057
S	0.0000	1.2700	0.00	0.00	0.00	(S)S_K	465
Fe	0.1357	1.1568	15.70	1.12	5.79	(S)Fe_K	4752
K	0.0015	1.0578	0.16	0.28	0.09	(S)K_K	84 ?
Na	0.0012	4.1821	0.50	1.07	0.45	(S)Na_K	61 ?
Mg	0.0037	2.6533	0.98	0.46	0.83	(S)Mg_K	345
Ti	0.1050	1.1549	12.13	0.74	5.21	(S)Ti_K	6559
O	0.0505	6.6145	33.43	2.78	43.03	(S)O_K	3672
Total			100.00		100.00		

Table 15 Claremont paint chip SEM elemental data for area shown in Figure 62

Sample /xd1/window1/#1,/Paint_CL28_2.spt
Accelerating Voltage: 20.00 keV
Takeoff Angle: 30.00 degrees
Library for system standards: /imix/quant/efficiency/default.dir

Elm	Rel. K	ZAF	Norm wt%	Prec.	Atomic %	Standard	Intensity	
Ti	0.0154	0.9817	1.51	0.25	1.18	(S)Ti_K	1483	
Ca	0.0090	1.0051	0.90	0.20	0.83	(S)Ca_K	1062	
Si	0.0113	2.0385	2.30	0.33	3.05	(S)Si_K	1900	
Al	0.0100	2.7415	2.73	0.49	3.76	(S)Al_K	1368	
S	0.0020	1.3972	0.28	0.05	0.33	(S)S_K	1463	
Fe	0.7121	1.0449	74.41	1.78	49.61	(S)Fe_K	38915	
K	0.0007	1.0884	0.08	0.22	0.07	(S)K_K	69	?
Na	0.0000	6.7324	0.00	0.00	0.00	(S)Na_K	32	?
Mg	0.0008	3.9440	0.31	2.26	0.47	(S)Mg_K	21	?
O	0.0852	2.0528	17.48	0.85	40.69	(S)O_K	9927	
Total			100.00		99.99			

Table 16 Claremont paint chip SEM elemental data for area 3 shown in Figure 64

Sample /xd1/window1/#1,/Paint_CL28_Big_3.spt
Accelerating Voltage: 20.00 keV
Takeoff Angle: 30.00 degrees
Library for system standards: /imix/quant/efficiency/default.dir

Elm	Rel. K	ZAF	Norm wt%	Prec.	Atomic %	Standard	Intensity	
C	0.0523	3.8765	20.28	2.41	33.84	(S)C_K	1721	
Ca	0.0925	1.0331	9.56	0.52	4.78	(S)Ca_K	8218	
Si	0.0360	1.5818	5.70	0.47	4.06	(S)Si_K	4185	
Al	0.0153	1.9362	2.96	0.42	2.20	(S)Al_K	1828	
S	0.0000	1.2865	0.00	0.00	0.00	(S)S_K	921	
Fe	0.1012	1.1614	11.75	0.97	4.21	(S)Fe_K	3747	
K	0.0017	1.0700	0.18	0.20	0.09	(S)K_K	142	?
Na	0.0018	3.9007	0.72	0.92	0.63	(S)Na_K	116	?
Mg	0.0047	2.5177	1.18	0.42	0.98	(S)Mg_K	527	
Ti	0.1082	1.1594	12.54	0.72	5.24	(S)Ti_K	7333	
O	0.0531	6.6179	35.13	2.59	43.97	(S)O_K	4439	
Total			100.00		100.00			

Table 17 Concord paint chip SEM elemental data for area shown in Figure 66

Sample /xd1/window1/#1,/C2_1.spt
Accelerating Voltage: 20.00 keV
Takeoff Angle: 30.00 degrees
Library for system standards: /imix/quant/efficiency/default.dir

Elm	Rel. K	ZAF	Norm wt%	Prec.	Atomic %	Standard	Intensity	
Ti	0.0055	1.1745	0.65	0.20	0.34	(S)Ti_K	539	
Ca	0.0123	1.1667	1.44	0.25	0.89	(S)Ca_K	1157	
Si	0.1365	1.8325	25.01	0.95	21.99	(S)Si_K	16301	
Al	0.0872	1.8462	16.10	0.76	14.74	(S)Al_K	11088	
S	0.0000	1.6351	0.00	0.00	0.00	(S)S_K	362	
Fe	0.1406	1.1320	15.92	1.07	7.04	(S)Fe_K	5392	
K	0.0391	1.2235	4.78	0.40	3.02	(S)K_K	3780	
Na	0.0014	3.1143	0.43	1.99	0.47	(S)Na_K	28	?
Mg	0.0319	2.0995	6.69	0.58	6.80	(S)Mg_K	3827	
O	0.0815	3.5562	28.98	1.68	44.73	(S)O_K	6905	
Total			100.00		100.02			

Table 18 Keene paint chip SEM elemental data for area shown in Figure 68

Sample /xd1/window1/#1,/K5_1.spt
Accelerating Voltage: 20.00 keV
Takeoff Angle: 30.00 degrees
Library for system standards: /imix/quant/efficiency/default.dir

Elm	Rel. K	ZAF	Norm wt%	Prec.	Atomic %	Standard	Intensity	
Ti	0.0028	1.2079	0.34	0.16	0.16	(S)Ti_K	301	
Ca	0.0142	1.1859	1.68	0.31	0.95	(S)Ca_K	1041	
Si	0.3369	1.4325	48.26	1.18	38.95	(S)Si_K	37101	
Al	0.0490	1.4958	7.33	0.48	6.16	(S)Al_K	5736	
S	0.0000	1.7835	0.00	0.00	0.00	(S)S_K	32	?
Fe	0.0365	1.1514	4.20	0.66	1.71	(S)Fe_K	1258	
K	0.0004	1.2868	0.05	0.07	0.03	(S)K_K	96	?
Na	0.0169	2.4127	4.08	0.51	4.03	(S)Na_K	1809	
Mg	0.0027	1.8448	0.49	0.25	0.46	(S)Mg_K	268	
O	0.0923	3.6366	33.57	1.91	47.56	(S)O_K	7075	
Total			100.00		100.01			

Table 19 Keene paint chip SEM elemental data for area 1 shown in Figure 70

Sample /xd1/window1/#1,/Paint_K30_1.spt
Accelerating Voltage: 20.00 keV
Takeoff Angle: 30.00 degrees
Library for system standards: /imix/quant/efficiency/default.dir

Elm	Rel. K	ZAF	Norm wt%	Prec.	Atomic %	Standard	Intensity
Ti	0.0062	1.1865	0.73	0.38	0.39	(S)Ti_K	263
Ca	0.0554	1.1481	6.36	0.54	4.11	(S)Ca_K	3656
Si	0.1669	1.7414	29.06	1.16	26.74	(S)Si_K	14936
Al	0.0571	1.8971	10.83	0.78	10.37	(S)Al_K	5175
S	0.0152	1.6414	2.49	0.33	2.01	(S)S_K	1951
Fe	0.1511	1.1346	17.14	1.26	7.94	(S)Fe_K	4422
K	0.0041	1.2320	0.51	0.18	0.34	(S)K_K	459
Na	0.0033	3.1048	1.01	0.86	1.13	(S)Na_K	159
Mg	0.0387	2.1200	8.20	0.74	8.71	(S)Mg_K	3457
O	0.0596	3.9739	23.67	1.96	38.26	(S)O_K	3557
Total			100.00		100.00		

Table 20 Keene paint chip SEM elemental data for area 2 shown in Figure 70

Sample /xd1/window1/#1,/Paint_K30_2.spt
Accelerating Voltage: 20.00 keV
Takeoff Angle: 30.00 degrees
Library for system standards: /imix/quant/efficiency/default.dir

Elm	Rel. K	ZAF	Norm wt%	Prec.	Atomic %	Standard	Intensity
Ti	0.0326	1.3452	4.39	0.59	2.22	(S)Ti_K	1642
Ca	0.4320	1.0445	45.12	1.27	27.36	(S)Ca_K	28082
Si	0.0271	1.5146	4.10	0.51	3.55	(S)Si_K	2122
Al	0.0179	1.8218	3.26	0.47	2.94	(S)Al_K	1613
S	0.0000	1.2181	0.00	0.00	0.00	(S)S_K	101 ?
Fe	0.0082	1.2007	0.98	0.52	0.43	(S)Fe_K	233
K	0.0021	0.9725	0.20	0.11	0.12	(S)K_K	293
Na	0.0009	3.5978	0.32	1.22	0.35	(S)Na_K	29 ?
Mg	0.0017	2.3581	0.39	0.30	0.39	(S)Mg_K	185
O	0.0457	9.0174	41.24	3.69	62.65	(S)O_K	2914
Total			100.00		100.01		

Table 21Whitefield paint chip SEM elemental data for area shown in Figure 72

Sample /xd1/window1/#1,/MT1_1.spt
Accelerating Voltage: 20.00 keV
Takeoff Angle: 30.00 degrees
Library for system standards: /imix/quant/efficiency/default.dir

Elm	Rel. K	ZAF	Norm wt%	Prec.	Atomic %	Standard	Intensity
Ti	0.0042	1.2160	0.51	0.15	0.24	(S)Ti_K	613
Ca	0.0395	1.1784	4.65	0.32	2.64	(S)Ca_K	5677
Si	0.2101	1.5850	33.30	0.78	27.00	(S)Si_K	43018
Al	0.0722	1.6043	11.59	0.49	9.78	(S)Al_K	14259
S	0.0000	1.6484	0.00	0.00	0.00	(S)S_K	84 ?
Fe	0.0463	1.1524	5.34	0.51	2.18	(S)Fe_K	3026
K	0.0314	1.2333	3.87	0.27	2.26	(S)K_K	5484
Na	0.0125	2.6809	3.36	0.38	3.33	(S)Na_K	2541
Mg	0.0067	1.9686	1.31	0.35	1.23	(S)Mg_K	906
O	0.0906	3.9827	36.07	1.56	51.34	(S)O_K	12500
Total			100.00		100.00		

Table 22 Whitefield paint chip SEM elemental data for area shown in Figure 74

Sample /xd1/window1/#1,/Paint_MT14_1.spt
Accelerating Voltage: 20.00 keV
Takeoff Angle: 30.00 degrees
Library for system standards: /imix/quant/efficiency/default.dir

Elm	Rel. K	ZAF	Norm wt%	Prec.	Atomic %	Standard	Intensity
Ti	0.0017	1.0023	0.17	0.06	0.12	(S)Ti_K	551
Ca	0.0172	1.0183	1.75	0.21	1.46	(S)Ca_K	2495
Si	0.0147	2.0195	2.97	0.30	3.53	(S)Si_K	3378
Al	0.0129	2.6825	3.45	0.41	4.27	(S)Al_K	2546
S	0.0031	1.4037	0.44	0.06	0.46	(S)S_K	2052
Fe	0.6322	1.0570	66.82	1.54	39.93	(S)Fe_K	41756
K	0.0000	1.0991	0.00	0.00	0.00	(S)K_K	59 ?
Na	0.0009	6.5011	0.61	0.57	0.88	(S)Na_K	167
Mg	0.0009	3.8442	0.36	1.36	0.50	(S)Mg_K	46 ?
O	0.1158	2.0226	23.43	0.92	48.87	(S)O_K	14483
Total			100.00		100.02		

Table 23 Whitefield paint chip SEM elemental data for area shown in Figure 76

Sample /xd1/window1/#1,/Paint_MT14_2.spt
Accelerating Voltage: 20.00 keV
Takeoff Angle: 30.00 degrees
Library for system standards: /imix/quant/efficiency/default.dir

Elm	Rel. K	ZAF	Norm wt%	Prec.	Atomic %	Standard	Intensity	
Ti	0.0002	0.9836	0.02	0.05	0.02	(S)Ti_K	89	?
Ca	0.0067	1.0123	0.68	0.14	0.62	(S)Ca_K	1281	
Si	0.0164	2.0451	3.35	0.28	4.33	(S)Si_K	4588	
Al	0.0128	2.7202	3.48	0.38	4.68	(S)Al_K	3028	
S	0.0010	1.4139	0.14	0.03	0.16	(S)S_K	1593	
Fe	0.7018	1.0454	73.37	1.42	47.67	(S)Fe_K	59567	
K	0.0011	1.0965	0.12	0.26	0.11	(S)K_K	106	?
Na	0.0004	6.6556	0.28	1.19	0.44	(S)Na_K	39	?
Mg	0.0004	3.9158	0.16	0.70	0.24	(S)Mg_K	42	?
O	0.0946	1.9445	18.40	0.71	41.73	(S)O_K	15136	
Total			100.00		100.00			

Table 24 Whitefield paint chip SEM elemental data for area shown in Figure 78

Sample /xd1/window1/#1,/Paint_MT19_1.spt
Accelerating Voltage: 20.00 keV
Takeoff Angle: 30.00 degrees
Library for system standards: /imix/quant/efficiency/default.dir

Elm	Rel. K	ZAF	Norm wt%	Prec.	Atomic %	Standard	Intensity
Ti	0.0007	1.2171	0.09	0.07	0.06	(S)Ti_K	162
Ca	0.0144	1.2202	1.76	0.44	1.14	(S)Ca_K	692
Si	0.3159	1.5120	47.77	1.59	44.22	(S)Si_K	20930
Al	0.0752	1.5003	11.28	0.80	10.86	(S)Al_K	5353
S	0.0171	1.7823	3.05	0.41	2.48	(S)S_K	1845
Fe	0.0820	1.1435	9.38	1.18	4.37	(S)Fe_K	1718
K	0.0335	1.2984	4.35	0.62	2.89	(S)K_K	1601
Na	0.0127	2.4084	3.07	0.63	3.46	(S)Na_K	874
Mg	0.0075	1.8089	1.35	0.92	1.44	(S)Mg_K	229
O	0.0399	4.4829	17.90	2.07	29.07	(S)O_K	1828
Total			100.00		99.99		

Table 25 Whitefield paint chip SEM elemental data for area shown in Figure 80

Sample /xd1/window1/#1,/Paint_MT19_2.spt
Accelerating Voltage: 20.00 keV
Takeoff Angle: 30.00 degrees
Library for system standards: /imix/quant/efficiency/default.dir

Elm	Rel. K	ZAF	Norm wt%	Prec.	Atomic %	Standard	Intensity	
Ti	0.0064	1.1656	0.75	0.39	0.39	(S)Ti_K	283	
Ca	0.0017	1.1670	0.20	0.28	0.12	(S)Ca_K	84	?
Si	0.2312	1.6435	37.99	1.14	34.09	(S)Si_K	24989	
Al	0.0583	1.7510	10.21	0.60	9.54	(S)Al_K	7056	
S	0.0005	1.7194	0.08	0.02	0.06	(S)S_K	638	
Fe	0.1597	1.1299	18.05	1.19	8.14	(S)Fe_K	5495	
K	0.0164	1.2543	2.06	0.31	1.33	(S)K_K	1500	
Na	0.0000	3.1576	0.00	0.00	0.00	(S)Na_K	77	?
Mg	0.0173	2.1055	3.64	0.44	3.77	(S)Mg_K	2047	
O	0.0784	3.4456	27.02	1.71	42.56	(S)O_K	5869	
Total			100.00		100.00			

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APPENDIX D3 – Petrographic Analysis

Petrographic Analyses

Cores from the pavement at five NH airports were obtained for analysis (Concord, Claremont, Keene, Whitefield, and Laconia). Aggregate was separated by NHDOT from the first 4 of those sites (Concord, Claremont, 2 from Keene, and 2 from Whitefield). Quarry sites are known for several of the sites, but not all.

Five to nine representative fragments were selected from each site, mounted in epoxy on clean petrographic slides, and cut to the standard 30 microns thickness for examination in both plane polarized and cross polarized light. Thin section blanks were also preserved for examination. Individual angular to subangular fragments ranged from ~1 to 2.5 cm. Photographs were taken of the fragments in the thin section blanks to illustrate size and shape characteristics (fragments are numbered for reference to those selected for more detailed description). A photomicrograph of nearly the entire slide was taken to illustrate gross texture and distribution of veins and some of the coarser grain features.

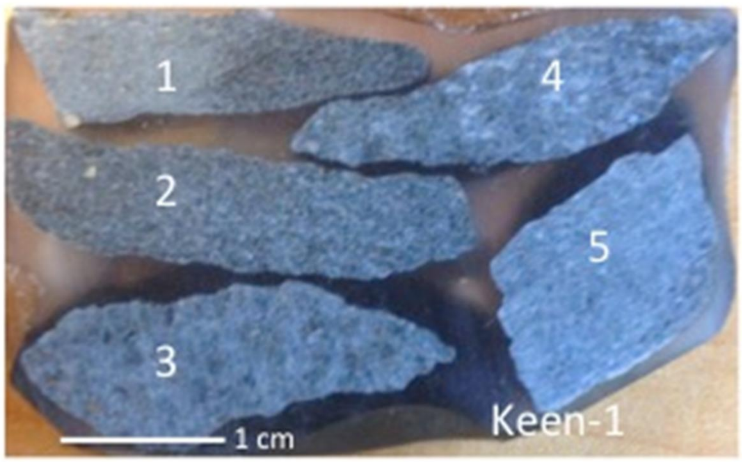
Photomicrographs of representative fragments were taken at 4x magnification and in plane polarized light (PPL) unless otherwise stated. Emphasis was placed on areas occupied by opaque iron oxide, iron sulfide, or iron oxyhydroxide minerals and their association with other ferromagnesian minerals (largely amphibole and biotite). The felsic minerals quartz and feldspar contribute little to the alteration problem. Bar scale is 500 microns (0.5 mm). Because the thin sections were completed with a coverslip, they were not polished and could not be viewed properly in reflected light. An additional step involving polishing the thin section blanks will be required if additional work on the opaque mineralogy is warranted.

Four 2-inch epoxy disks filled with aggregate were prepared from two cores from both Keene (5 and 6) and Whitefield (HEI T and HEI 1), These were cut and polished. Each was found to be moderately magnetic and thus confirms the presence of magnetite and/or pyrrhotite. These two minerals are naturally occurring magnetic minerals that are commonly found in igneous and metamorphic rocks, particularly in metavolcanic rocks like the Ammonoosuc Volcanics and metaigneous rocks of the Oliverian domes of western New Hampshire. The polished disks were also examined microscopically under reflected light, and even though the disks were not polished to a mirror surface, sufficient reflectance was observed to identify brassy colored sulfide minerals, most likely pyrite and/or pyrrhotite. Magnetite (Fe_3O_4) and both pyrite (FeS_2) and pyrrhotite ($FeS_{(1-x)}$) are easily oxidized during weathering to produce FeOOH.

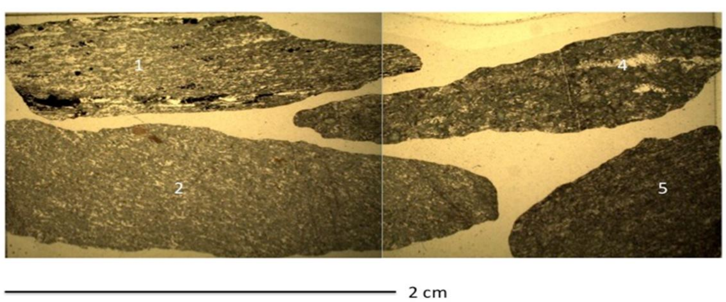
Diliant Hopkins Airport, Keene, NH

K-1 Aggregate source: Pike Industries quarry, West Lebanon, NH. Hornblende schist mapped as Ordovician Ammonoosuc Volcanics (Lyons and others, 1997)

K-1 Five fragments of medium to coarse-grained amphibolite in thin section blank and photomicrograph

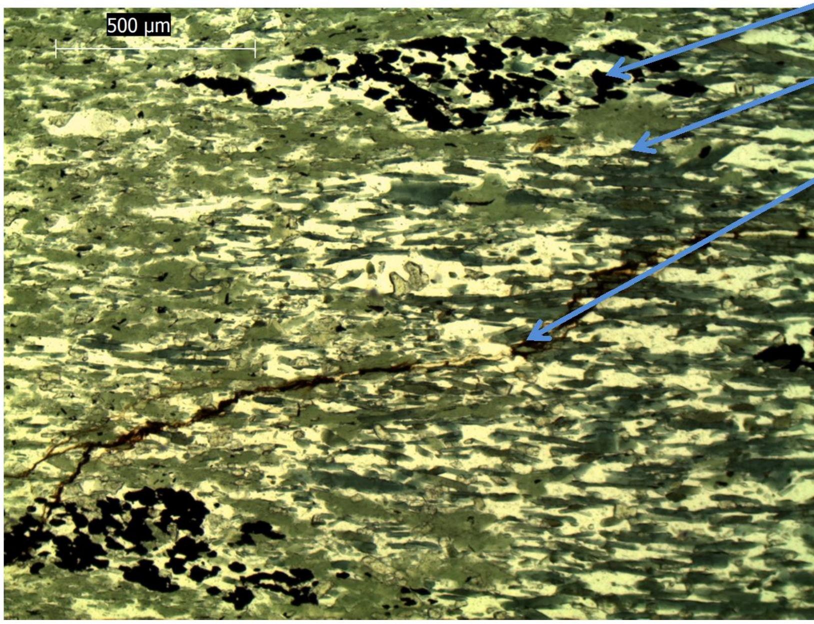


K 1 Diliant Hopkins Airport, Keene, NH

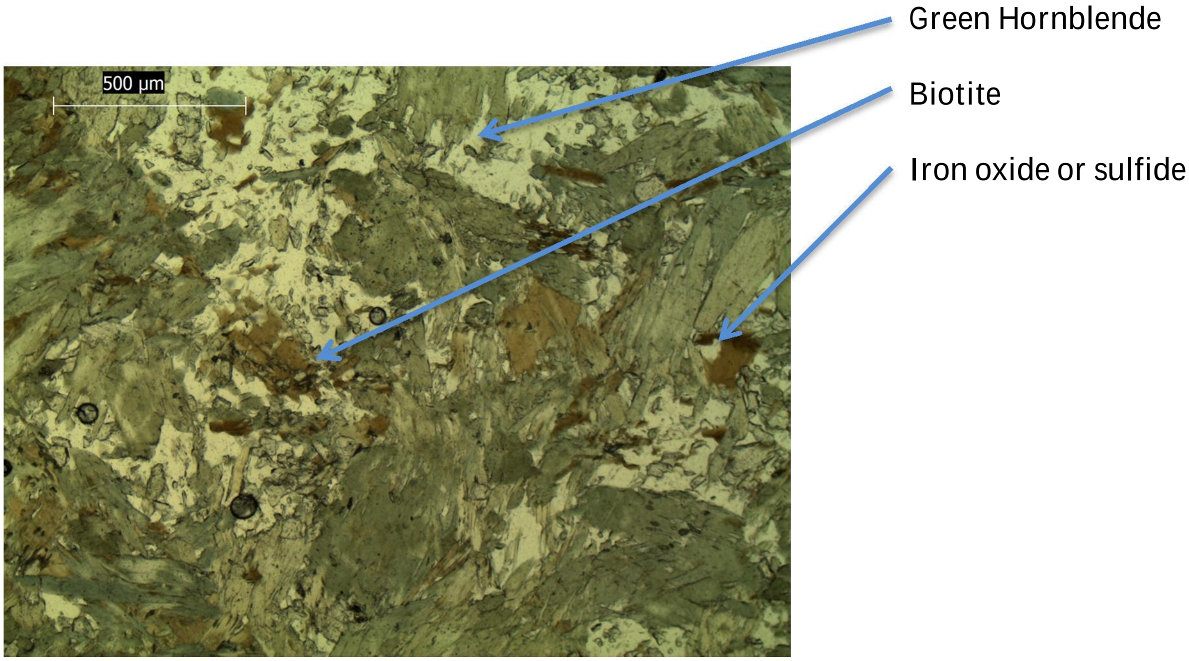


Needle shaped pleochroic pale green to blue green 1-3mm hornblende crystals (mode ~70%) are oriented roughly parallel to one another and define the principal schistosity. Undulatory quartz and plagioclase feldspar, some with vague relict zoning and preserved polysynthetic twinning, together occupy ~20-25% of the thin section. Epidote, biotite, secondary chlorite (an alteration product principally of amphibole and biotite when present), accessory sphene, and variable percentages (0-perhaps as much as 5%) of one or more opaque minerals complete the metamorphic mineral assemblage. The opaque mineralogy is either the iron oxide (MAGNETITE) and/or the iron sulfide (PYRITE). The former is the likely cause of the variable magnetic character of the samples. Pyrite is identified by a brassy reflectance when light is shown from above. Very minor iron oxyhydroxide (FeOOH) was identified as an occasional fracture filling or along a few grain boundaries

The following photomicrographs illustrate the relationship between the opaque (iron oxide and iron sulfide) minerals and the surrounding minerals.



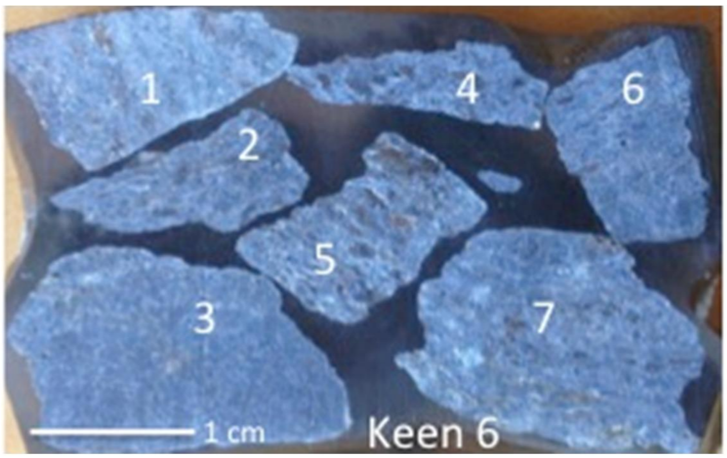
K-1-1 (Sample K-1, fragment 1) Strongly oriented green amphibole, clear quartz and feldspar, poikiloblastic pyrite (black) and cross cutting dark brownish black alteration fracture filling (probably FeOOH). 4X, PPL



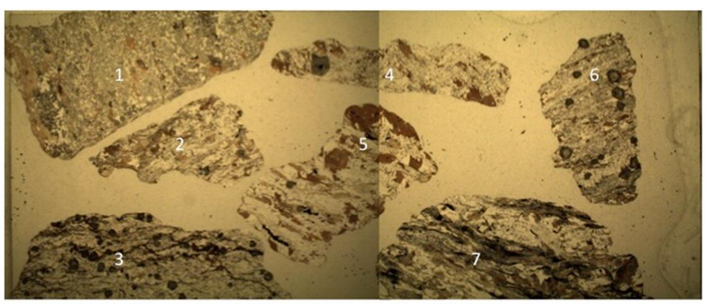
K-1-3 Thin section of coarse grained amphibolite cut approximately parallel to foliation making individual grains appear ‘flaky’ and oriented in a spray-like fashion. Biotite occurs as light brown flakes, plagioclase and quartz are colorless and epidote occurs as high relief translucent grains. There is only a trace of opaque in this slide as well as a few bubbles (circular) in the epoxy. 4X, PPL

K-6 Aggregate source: Lane Construction, quarry unknown, varied rock types includes garnet biotite schist, garnet-bearing micaceous quartzite, and sillimanite-garnet-biotite schist.   Probable Silurian Rangeley and/or Devonian Littleton Formations

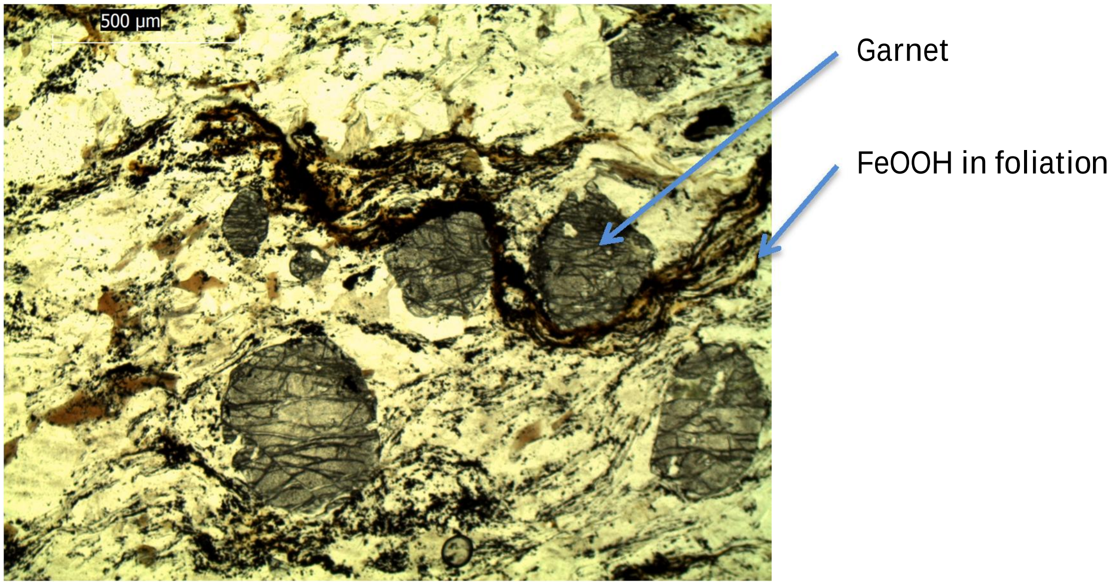
K-6 Seven pelitic and felsic fragments are exposed in this sample. They consist of garnet-biotite and silllimanite-garnet-biotite schists and micaceous garnet quartzite



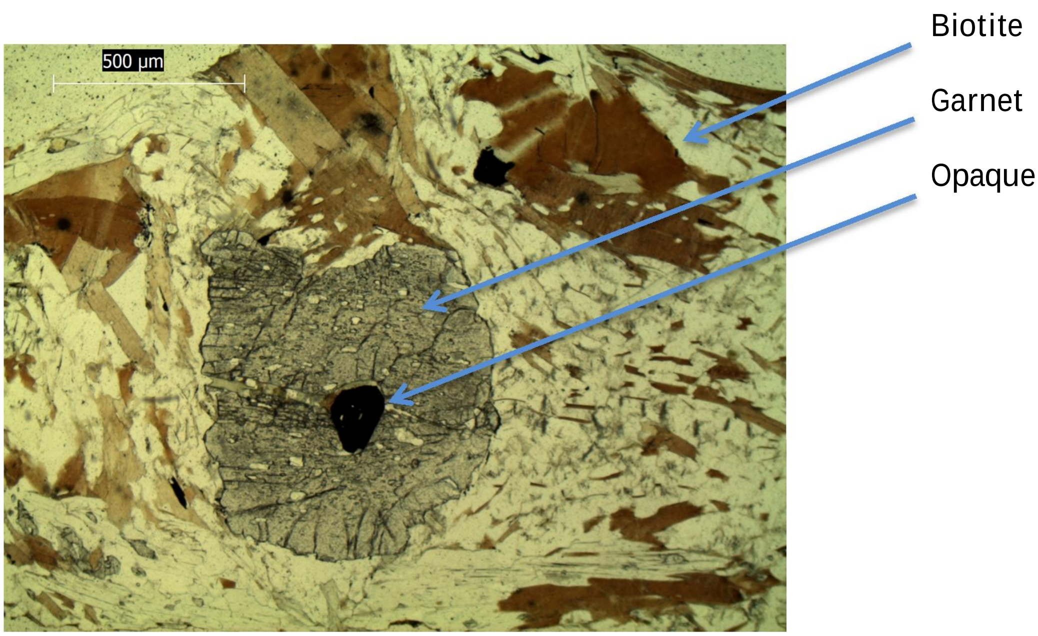
K 6 Diliant Hopkins Airport, Keene, NH



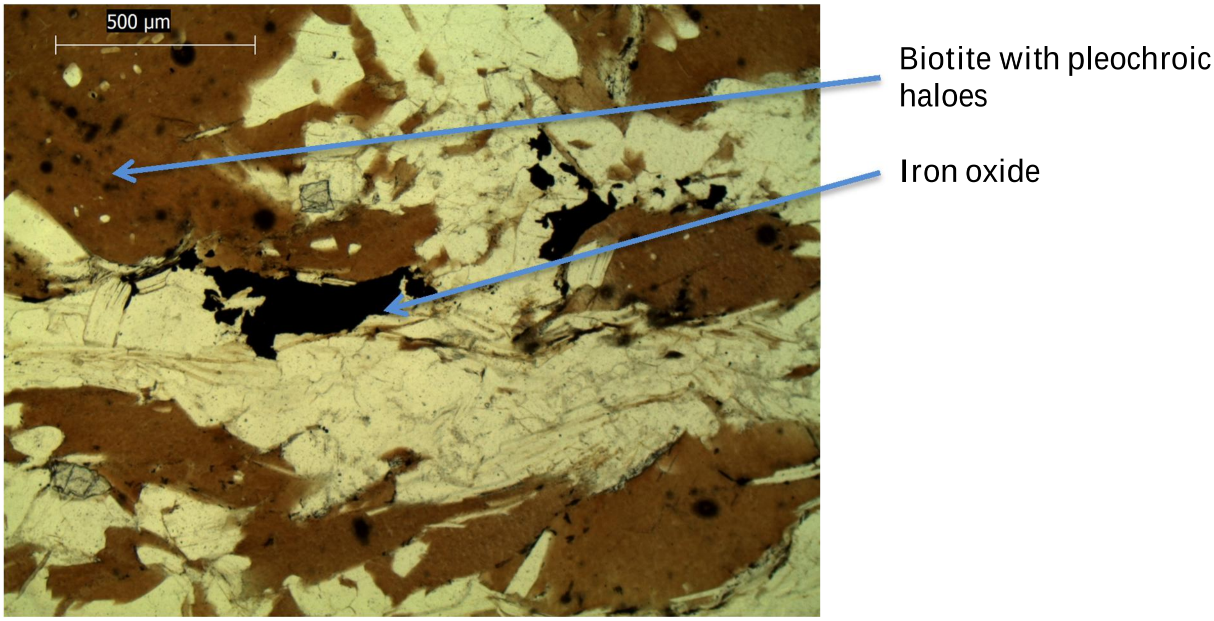
1 cm



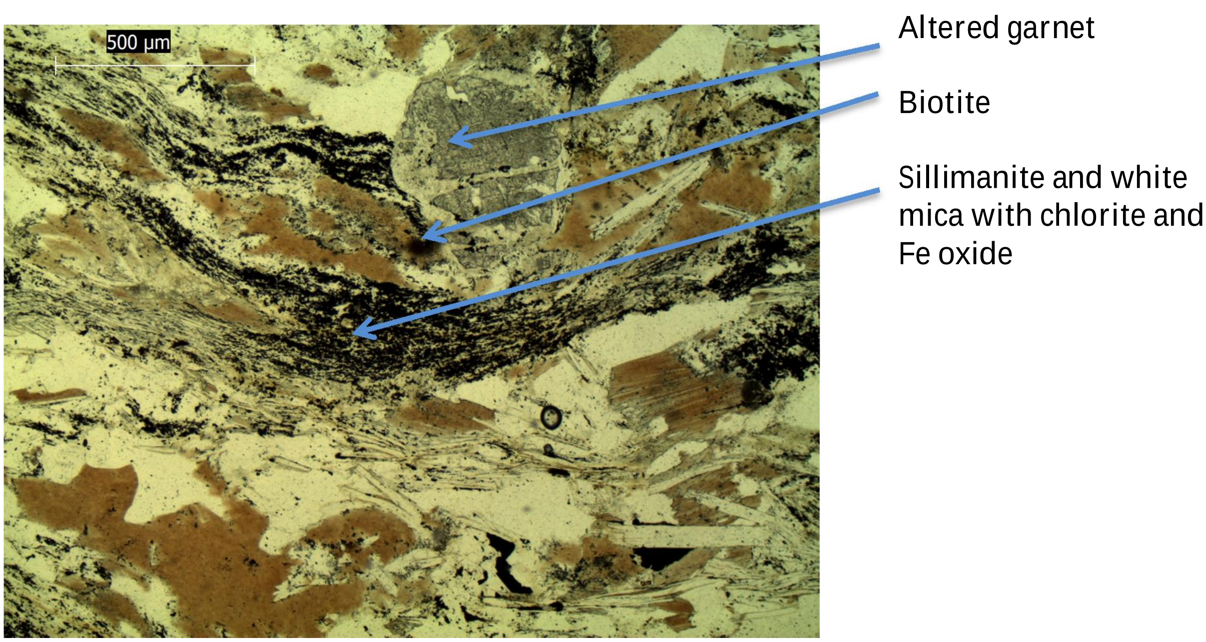
K-6-3 Garnet micaceous quartzite with ~5% opaque (likely magnetite as this fragment is weakly magnetic). Six garnet grains (porphyroblasts) stand out in this image. Biotite foliation is deflected around the garnet grains and is stained by iron oxide hydroxide (FeOOH). 4x, ppl



K-6-4 Garnet mica schist. Large garnet grain in center of field of view contains inclusions of quartz (clear grains) and one opaque. Variably brown pleochroic biotite defines foliation; pale greenish white mica (muscovite) occurs intergrown with biotite (best example along the bottom of the image). 4x, ppl



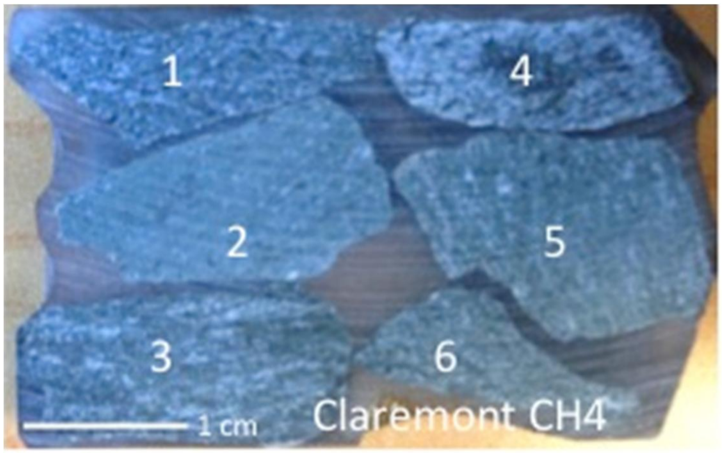
K-6-5 Mica schist is dominated with biotite, muscovite, and quartz.   Iron oxide opaque occurs at the margins of biotite. Small circular black spots throughout the brown biotite represent radiation damage cause by small zircon grains that carry minute quantities of uranium. 4x, ppl.



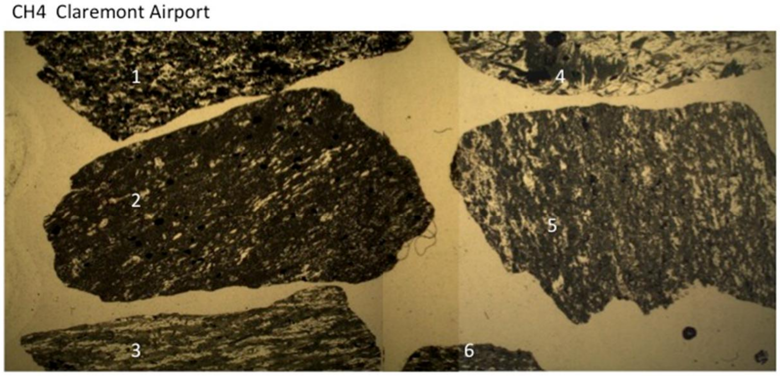
K-6-7 Slightly altered sillimanite-garnet-biotite schist.   Garnet alteration to chlorite and white mica, brown biotite, sillimanite sprays, now white mica with intergranular opaque. Clear areas are quartz, feldspar, and white mica. 4x, ppl.

Claremont Airport, Claremont, NH

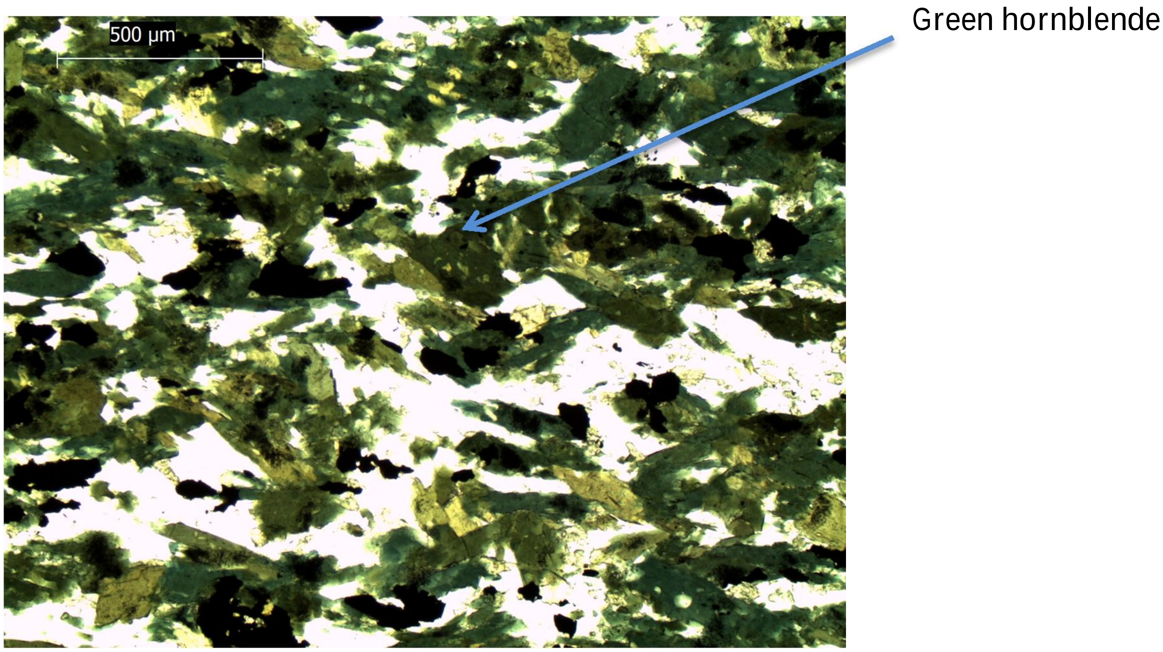
CH 4 (CHN4 6) consists of 6 fragments of amphibolite, most likely from Pike Industries quarry in West Lebanon, NH



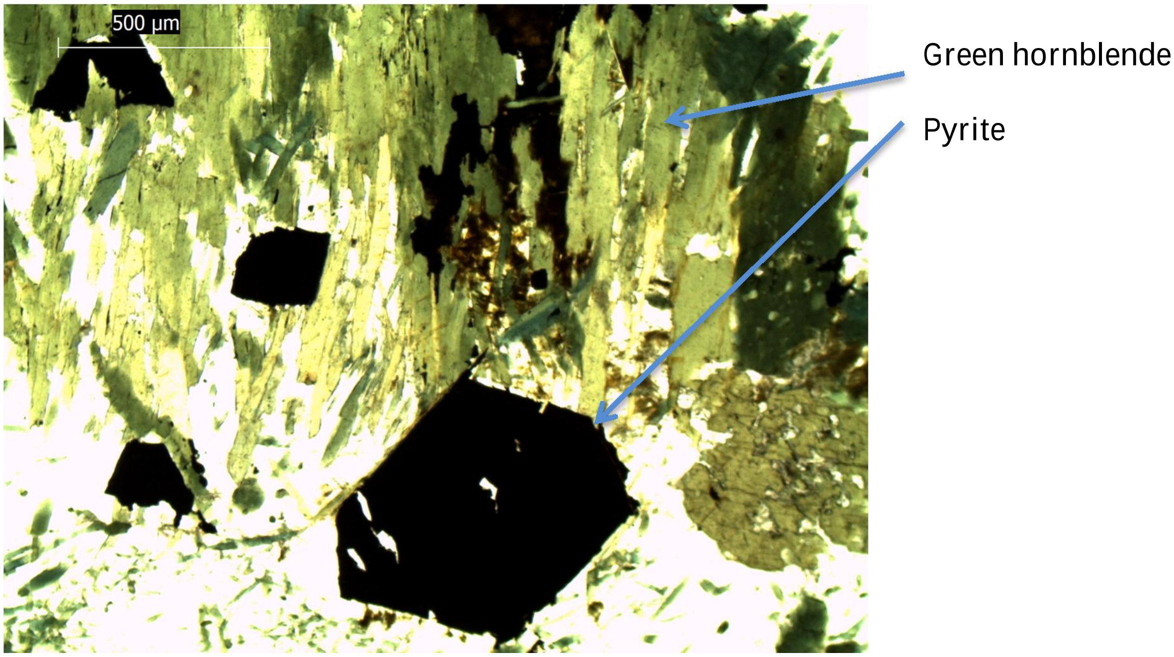
CH4 Claremont Airport



2 cm



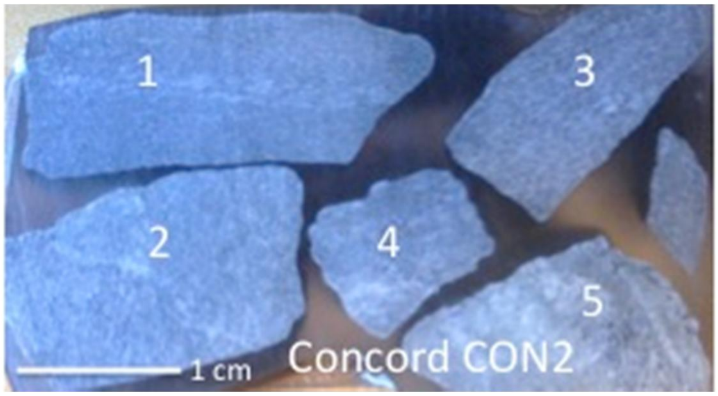
CH-4-1. Fine to medium grained well foliated light to dark green pleochroic hornblende comprises 30-75% of the aggregate. Plagioclase, commonly twinned and quartz occur as clear grains in plane polarized light make up as much as 70%, but typically barely half that. Epidote and one or more opaque minerals complete the assemblage. The iron bearing phases (magnetite and pyrite) may account for as much as 5% by mode. A few larger euhedral grains show clear brassy reflectance confirming pyrite; more often, however, the grains occur as irregular clusters. 4x, ppl

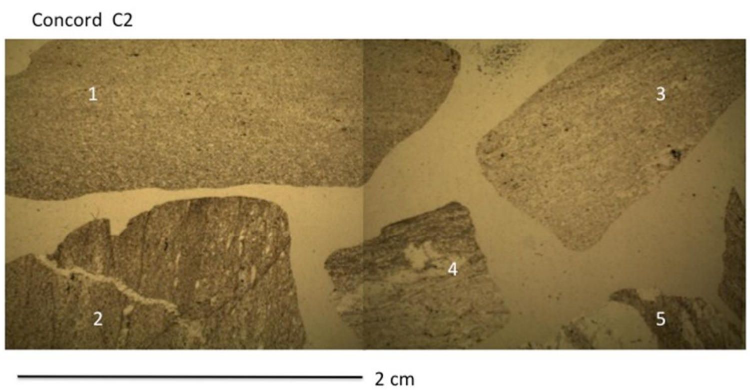


CH-4-4 Pyrite euhedra surrounded by sprays of amphibole, with interstitial quartz and plagioclase feldspar. 4x, ppl

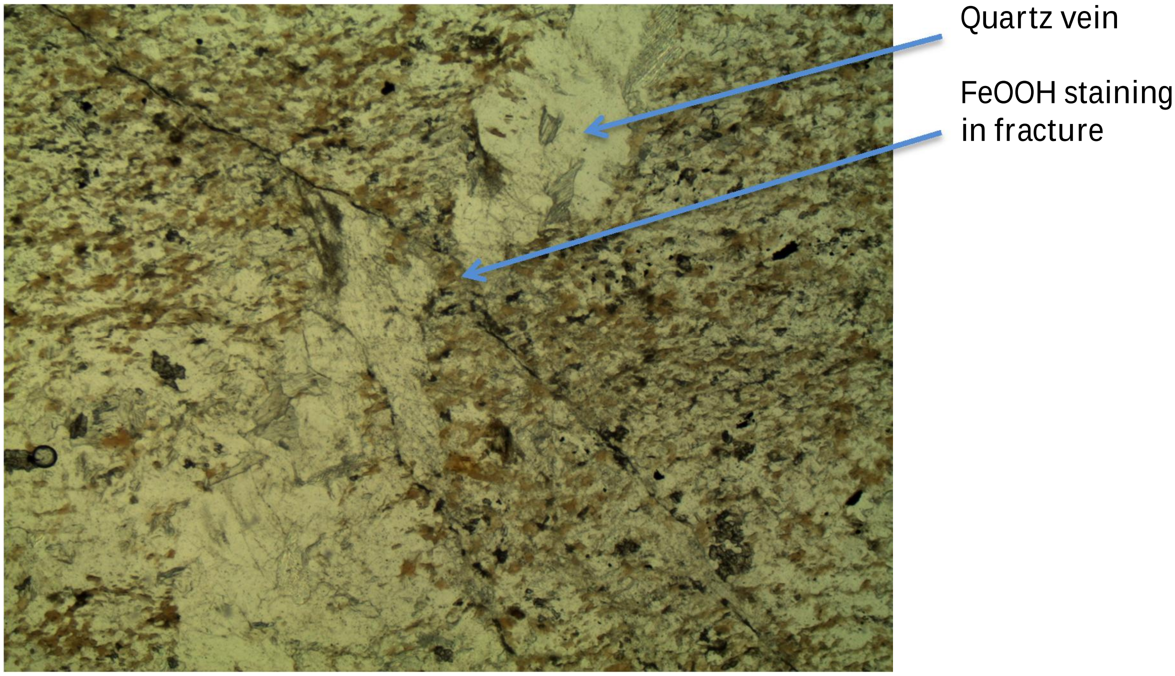
Concord Airport, Concord, NH

C-2 (Con 2) consists of 5 fragments from the Continental Paving quarry in Litchfield, NH

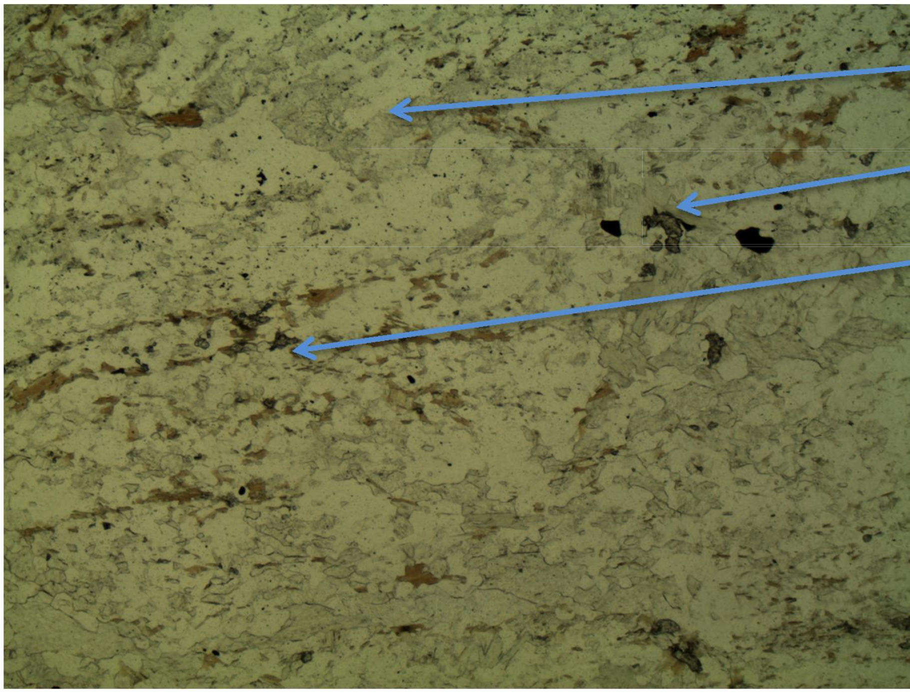




The fragments are fine grained variably calcareous biotite granofels, most likely from the Silurian Berwick Formation..



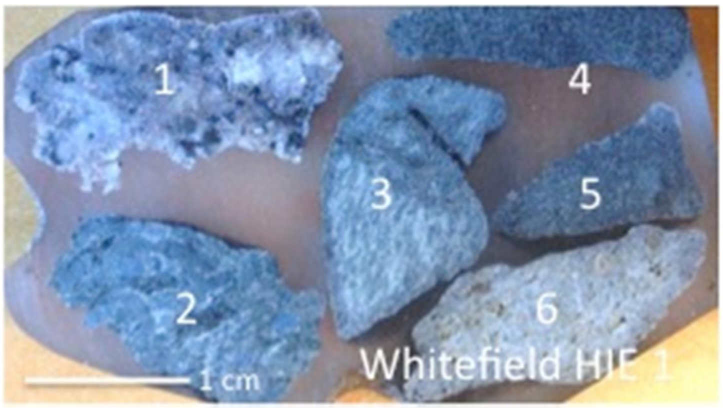
Con 2-2   The rock consists of fine grained biotite, usually weakly aligned to define foliation, quartz (sometimes as fracture fillings) and plagioclase feldspar, and carbonate. The latter occurs as intrafolial grains and occasionally cross-cutting veins. Opaque minerals are sparse, but secondary FeOOH staining is seen along foliation surfaces and in fractures. Note crosscutting quartz vein and iron stained fracture. Fine grained biotite defines weak foliation. Quartz, plagioclase feldspar, and white mica complete the assemblage. 4x, ppl

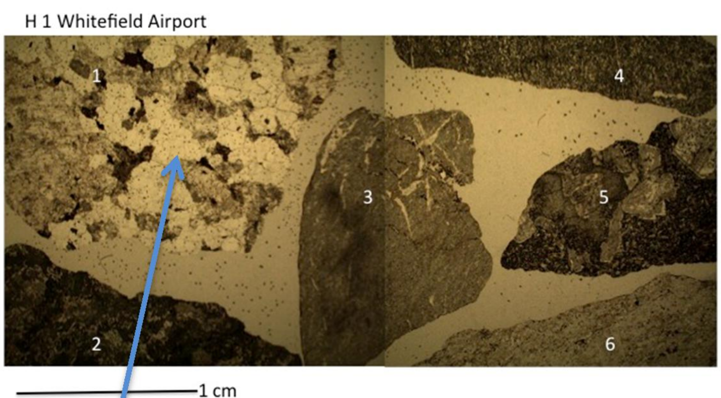


Con 2-4 Irregular carbonate vein cutting subhorizontal foliation from top left corner to right center of the slide. Biotite defines the weak foliation in the center and black grains are iron-bearing opaques. 4x, ppl

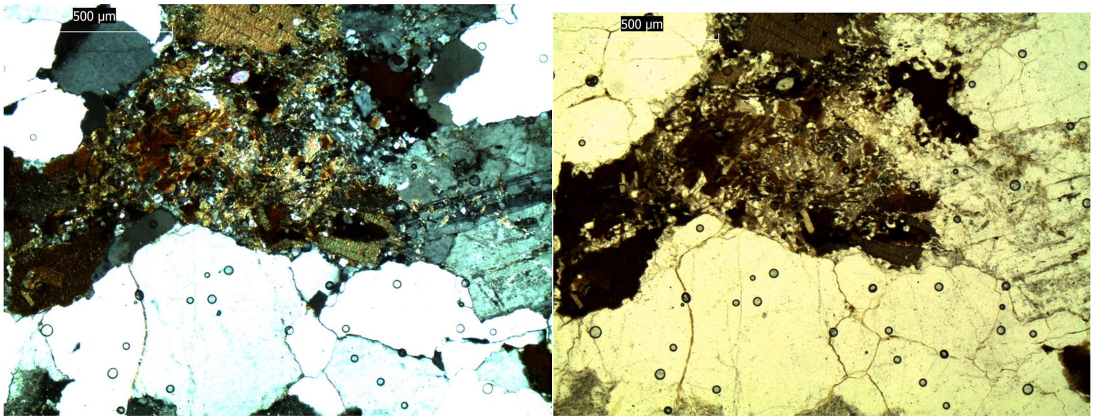
Mt. Washington Airport, Whitefield, NH

H-1 Six fragments from a quarry in Milan, NH (Pike) and consists of a varied assemblage of rock types including granite, amphibolite (mafic metavolcanic) and felsic metavolcanics most likely from Ordovician Oliverian series dome gneisses and overlying Ammonoosuc volcanics.

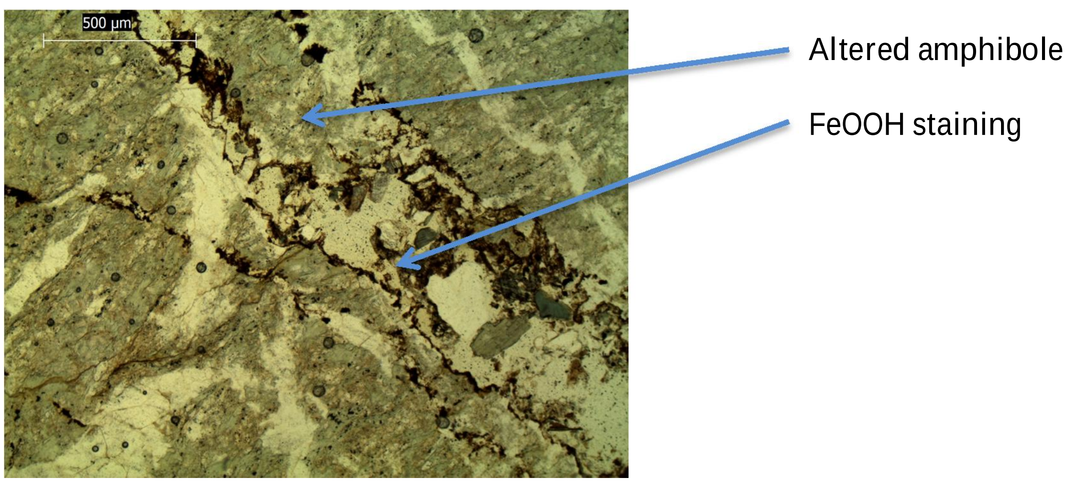




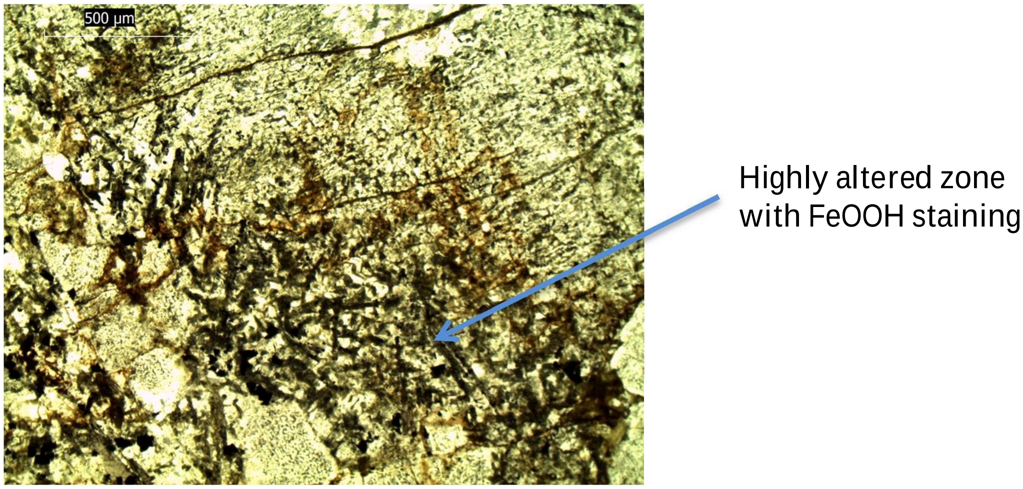
Granite, note interlocking texture, clear grains are quartz, cloudy minerals are feldspars, darkest grains are biotite



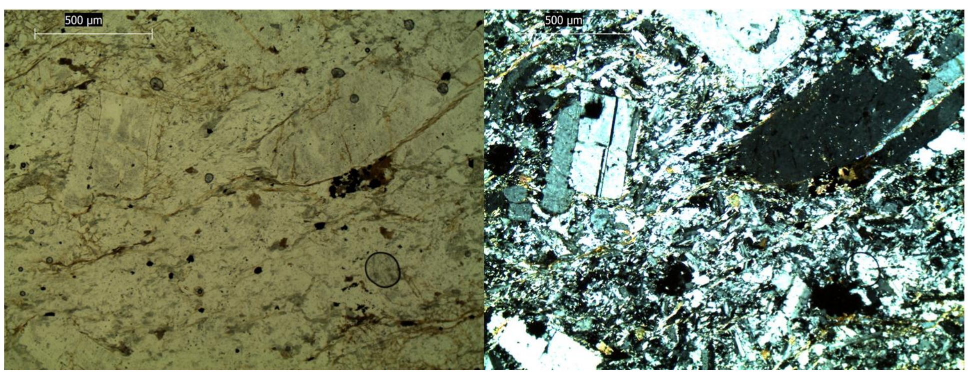
H-1-1 Granite shown in xpl and ppl. Quartz grains are irregularly shaped and dominate the lower third of the image. Twinned plagioclase feldspar and perthitic alkali feldspar and altered biotite complete the common assemblage. Little or no primary iron oxide opaques are visible in this image, but FeOOH staining is present in association with biotite



H-1-3 Amphibolite, probably metabasalt of the Ammonoosuc Volcanics, is altered to a chlorite-rich schist   FeOOH staining occurs along grain and vein boundaries. 4x, ppl

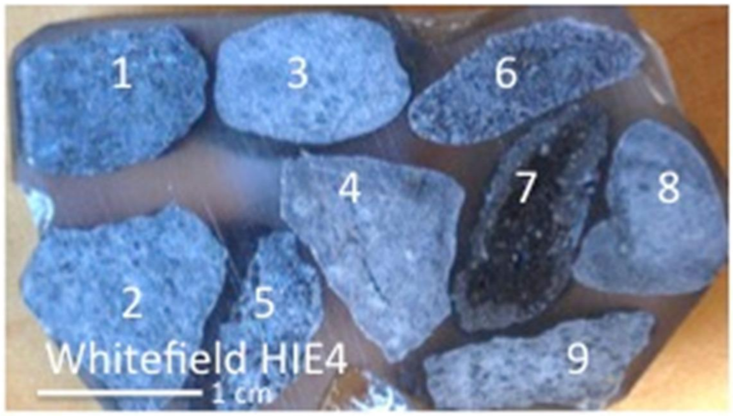


H-1-5 Altered metavolcanic porphyry. Coarse plagioclase grains are zoned, mantled, and altered to fine-grained white mica, set in a fine-grained matrix. Ferromagneisan and opaque minerals are altered to iron oxide hydroxide

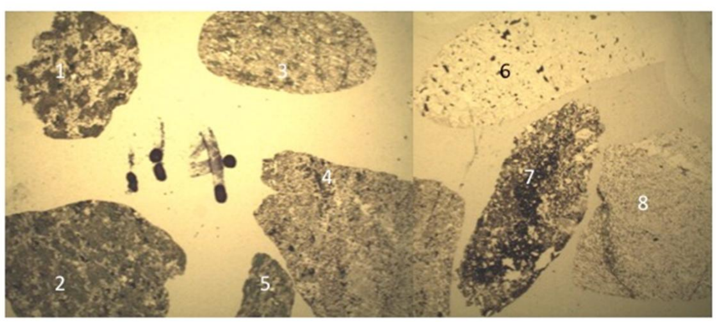


H-1-6 Felsic metavolcanic porphyry shown in ppl and xpl contains randomly oriented twinned plagioclase phenocrysts set in a fine-grained quartz-feldspar matrix. Iron oxide hydroxide alteration is apparent along grain boundaries and a few fractures. 4x

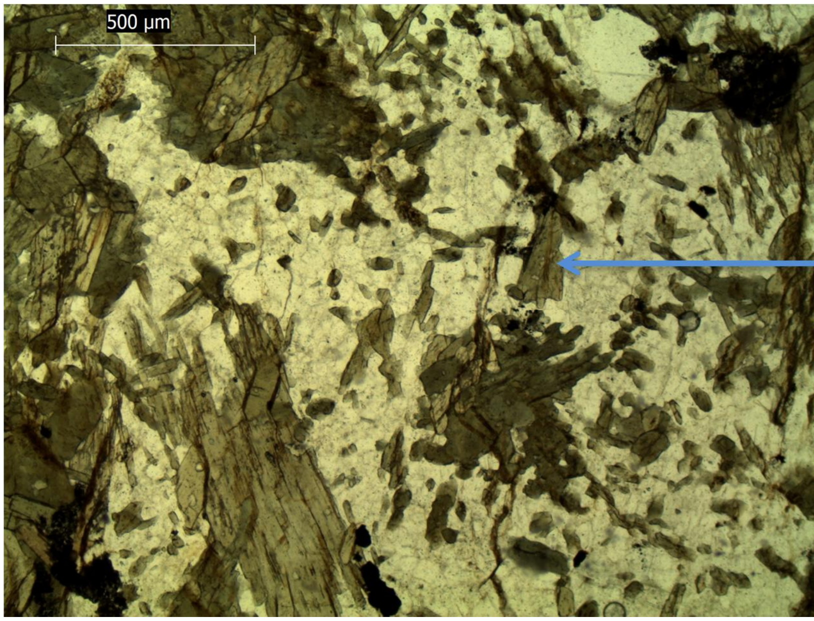
H-4 consists of 9 fragments that include granitic, dioritic and gabbroic rocks, felsic metavolcanics, and an unusual limonite(?) cemented breccia (7). Quarry site thought to be in the Gorham, NH, vicinity.



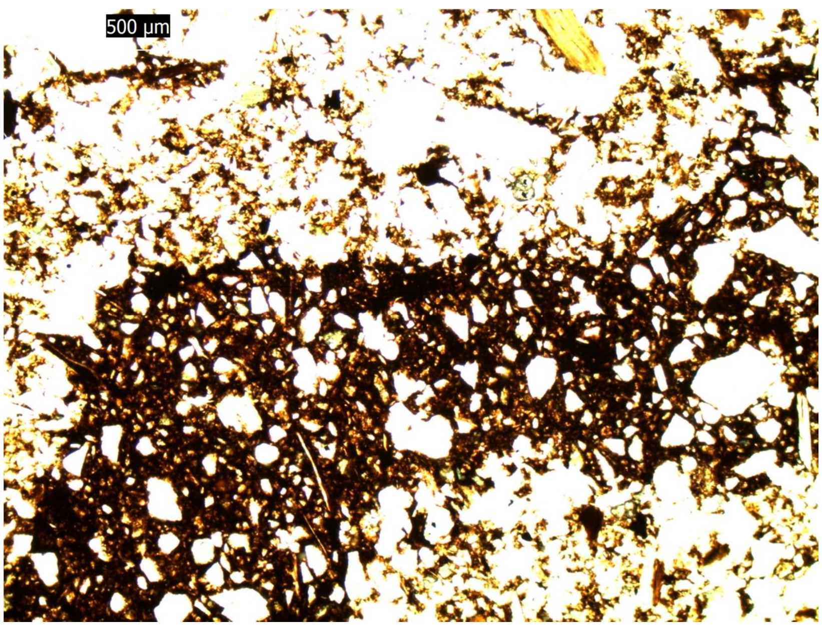
H 4 Whitefield Airport



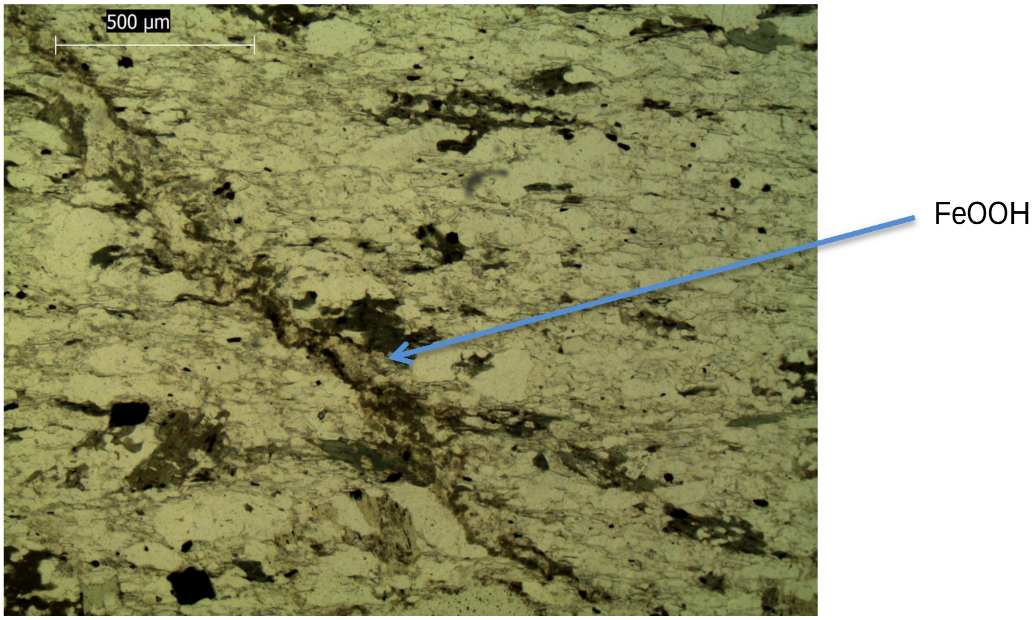
1 cm



H-4-1 Metadiorite composed of light to dark green pleochroic hornblende ranging in sized from .5 to 1 mm in length. Smaller grains are clustered in a random pattern within a fine-grained matrix of quartz and plagioclase feldspar. Opaque iron oxides occur adjacent to hornblende grains. Pyrite is also present in minor quantities and both show some FeOOH alteration.



H-4-7 Iron oxide cemented breccia containing a variety of incorporated minerals, most are angular particles of quartz, plagioclase, altered amphibole, and biotite. Crosscut by .5mm vein FeOOH vein choked with the same mineral assemblage. 4x, ppl.



H-4-9 Felsic metavolcanic rock with green biotite and white mica defining foliation. Plagioclase and quartz make up the clear minerals. Opaque mineralogy is dominated by pyrite. FeOOH present in crosscutting vein.

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Appendix E

NHDOT

Paint and Pavement Construction Submittal Data

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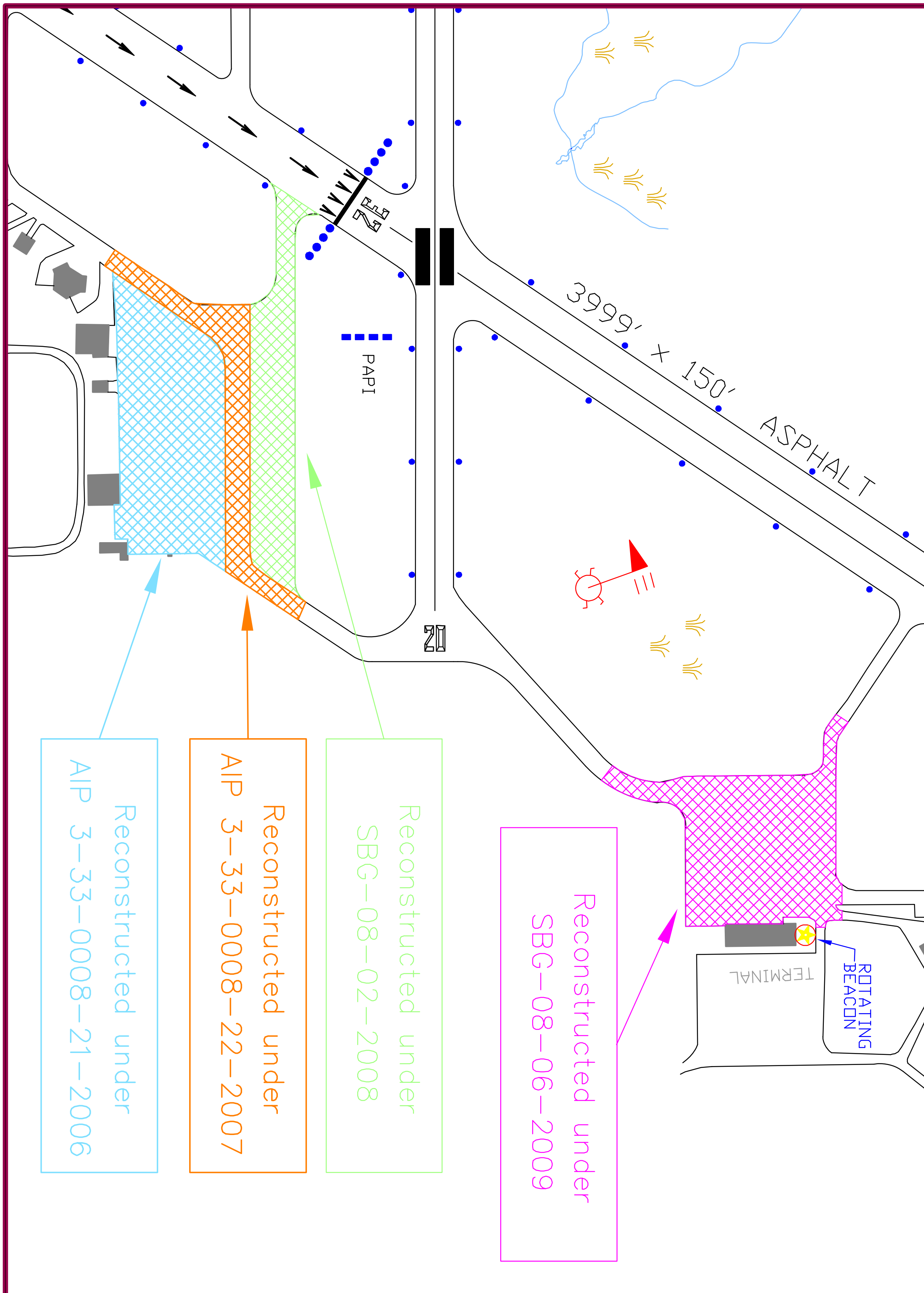
Airport	**Project Number/Construction Submittal Data**
Keene	Keene – Airport Pavement Projects Map
	SBG-08-06-2009/Terminal Apron Bituminous Concrete Testing Summary
	SBG-08-06-2009/Terminal Apron Paint Data
	SBG-08-02-2008 (assumed)/ General Expansion of Taxiway A Pavement Mix Design
Claremont	Claremont – Airport Pavement Projects Map
	SBG-02-03-2010/Taxiway C West Pavement and Soils Testing Report
	SBG-02-03-2010/Taxiway C West Mix Design
	SBG-02-01-2008/Taxiway C East Test Results
	SBG-02-01-2008/ Taxiway C East Mix Design
	3-33-0002-16-2005/Construct 6-unit Hangar Building and Reconstruct Taxiway B
Whitefield	Whitefield – Airport Pavement Projects Map
	SBG-17-03-2010/ Apron Ramp Reconstruction Pavement Mix Design
	SBG-17-03-2010/ Apron Ramp Reconstruction Extraction and Density Tests
	3-33-017-01-2008/Taxiway A Paint Data
	3-33-017-15-2007/Taxiways A, C and Ramp Paint Data
	3-33-0017-15-2007/Taxiway & Apron - Mix Design Pike
	3-33-0017-13-2005/Runway - Pavement Mix Design
	3-33-0017-13-2005/Runway - HMA Extraction and Density Tests
Laconia	Laconia – Airport Pavement Projects Map
	SBG-09-03-2009 Terminal Apron Paint Submittal
	SBG-09-03-2009 Terminal Apron HMA Mix Design - CPI
	SBG-09-02-2009 Taxiway C Pavement Testing

	SBG-09-02-2009 Taxiway C Mix Design - Pike
	3-33-0009-17-2007 Itinerant Apron Phase 2 Mix Design
	3-33-0009-16-2005 Runway 8-26 and Taxiway B Mix Design
	3-33-0009-16-2005 Runway 8-26 and Taxiway B Asphalt Core and Plant Testing Lots 4-9
	3-33-0009-15-2004 Itinerant Apron Phase 1 Pavement Testing
Concord	Concord – Airport Pavement Projects Map
	3-33-0004-15-2002/Concord Runway 12-30 Pavement Test Results

Airport maps follow this listing. The submittal data is voluminous and is not included.



SHEET TITLE
Dillant-Hopkins Airport

PROJECT
Pavements

DRAWING
1

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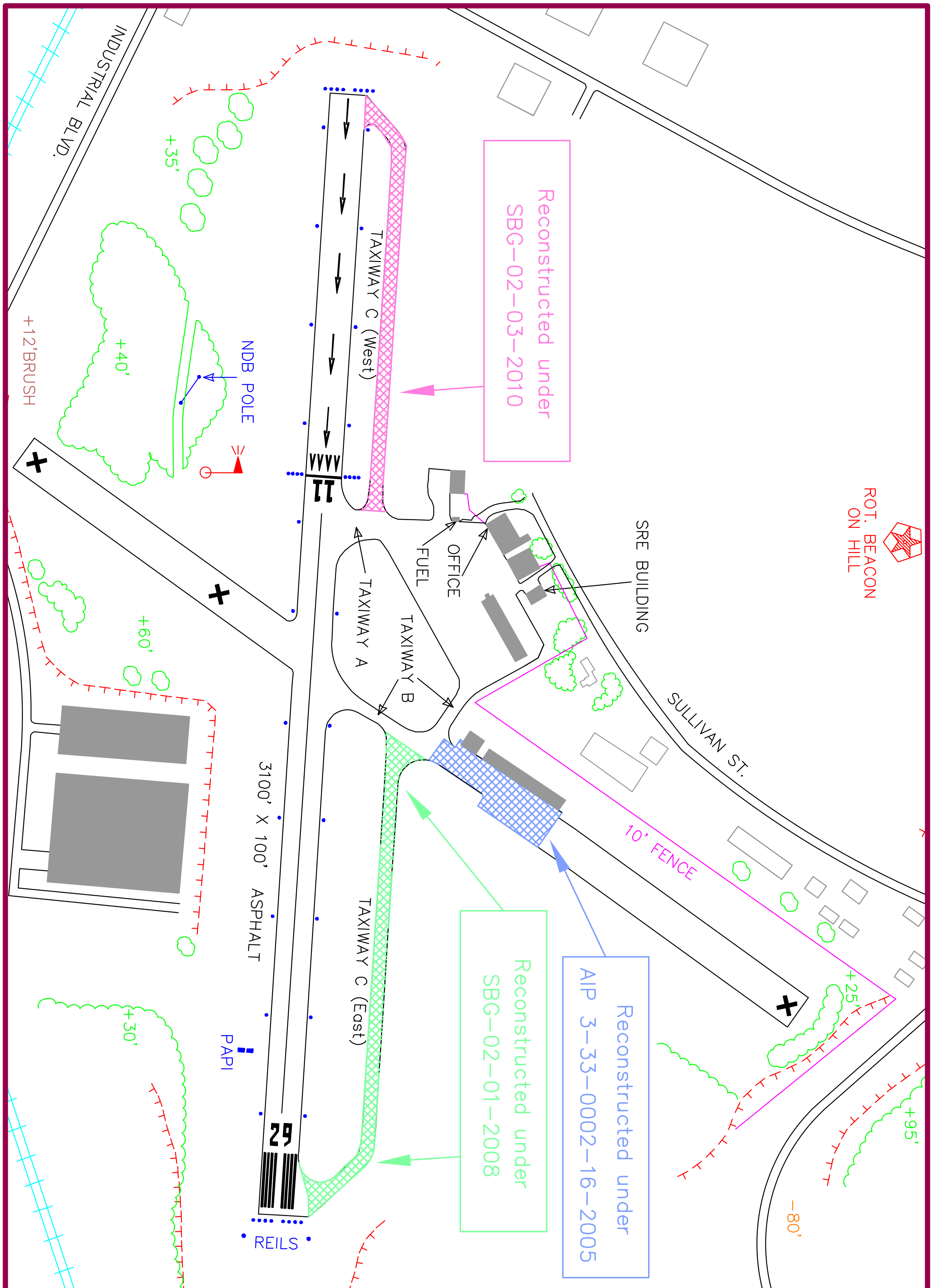
PROJECT NO: ----
DATE:
CAD DWG FILE: PAVEMENTS - EEN.DWG
DRAWN BY: ####
CHK'D BY: ####



SHEET TITLE

Claremont Municipal Airport

PROJECT

Pavements

REF:

PROJECT NO: ----

DATE:

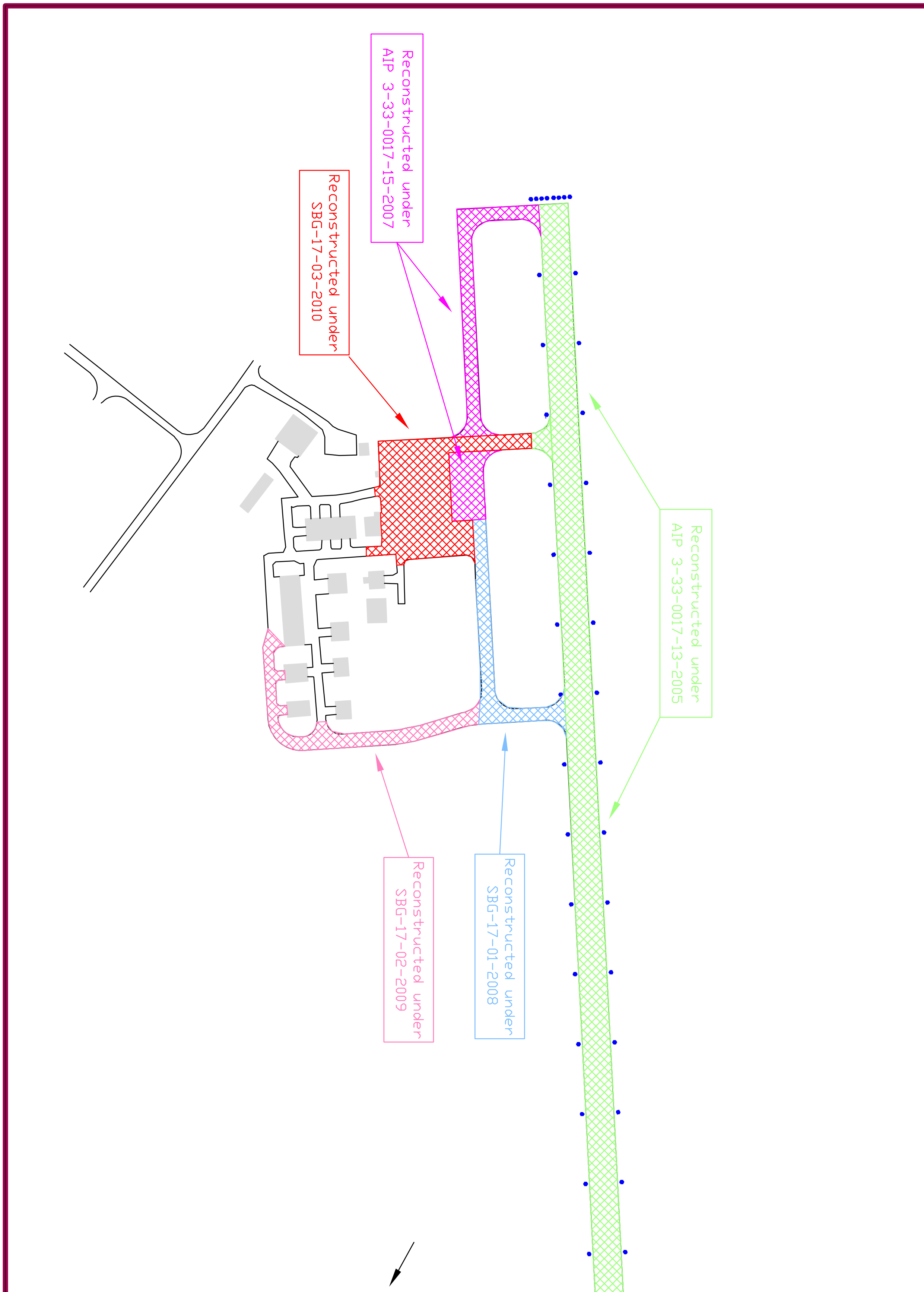
CAD DWG FILE: PAVEMENTS - CNH.DWG

DRAWN BY: ####

CHK'D BY: ####

DRAWING

1



SHEET TITLE

Mount Washington Regional Airport

PROJECT

Pavements

DRAWING

1

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PROJECT NO: ----
DATE:
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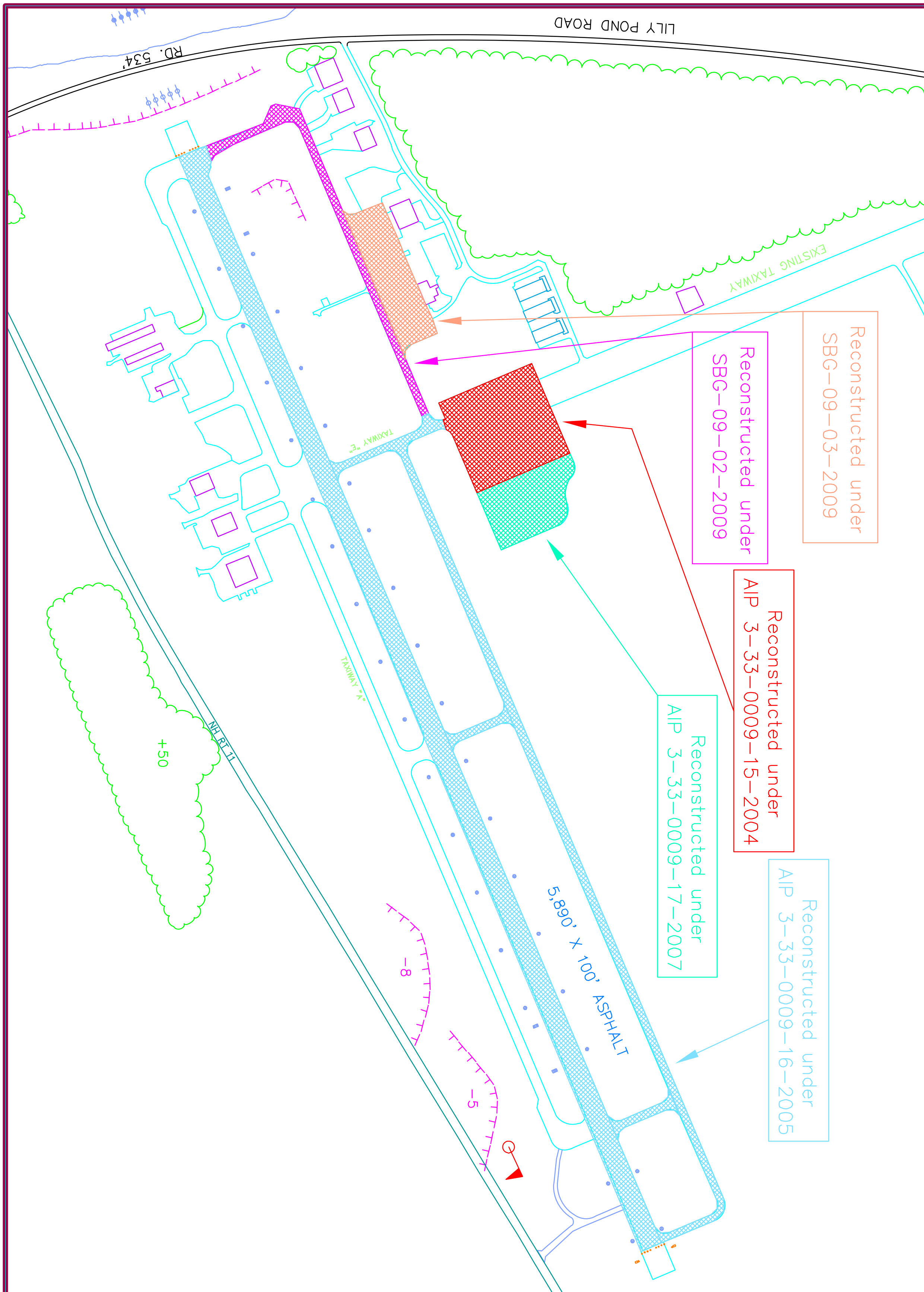
DRAWN BY: ####
CHK'D BY: ####



SHEET TITLE

Laconia Municipal Airport

PROJECT

Pavements

DRAWING

1

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PROJECT NO: ----

DATE:

CAD DWG FILE: PAVEMENTS - C.DWG

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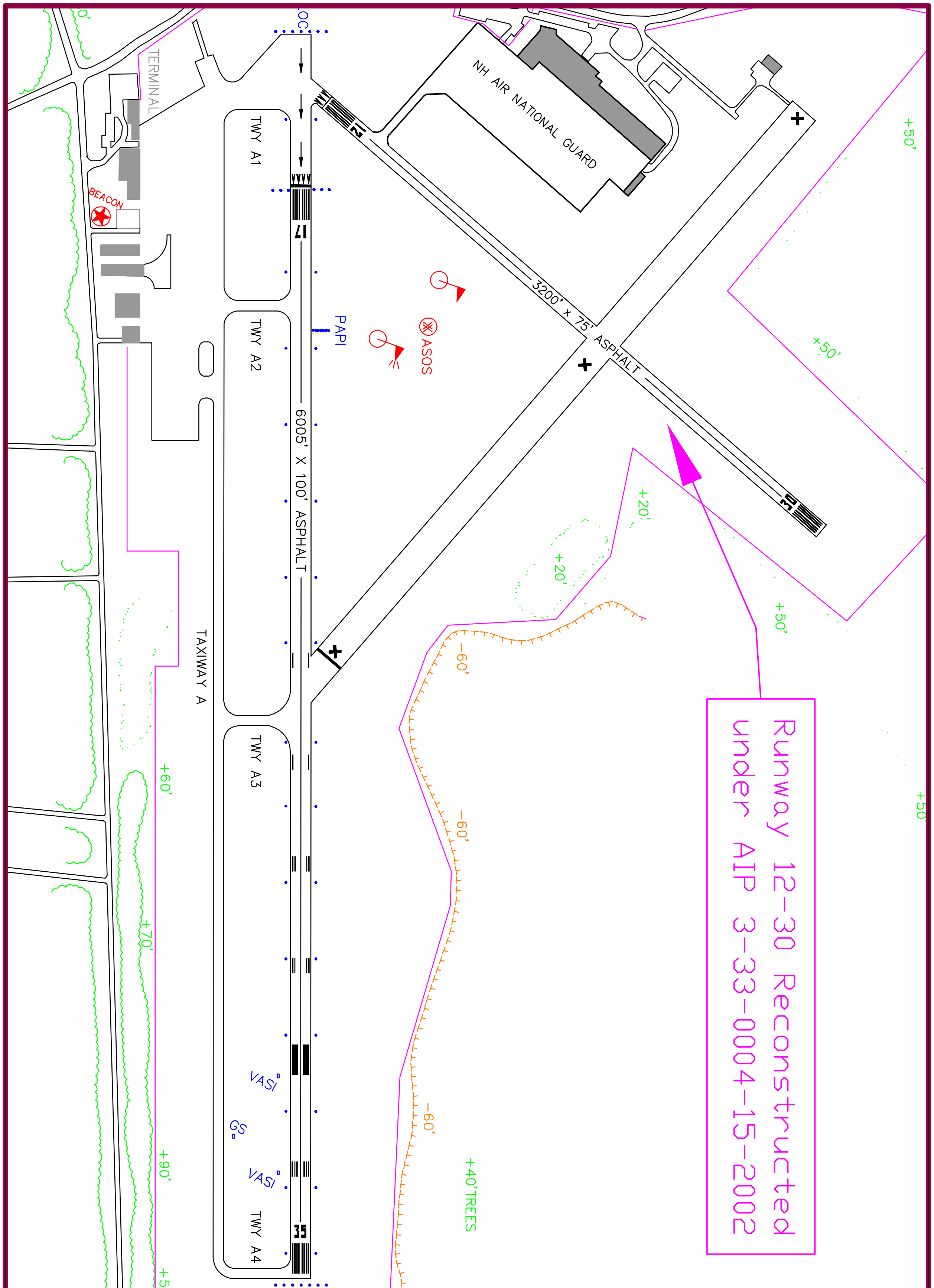
CHK'D BY: ####



SHEET TITLE

Concord Municipal Airport

PROJECT

Pavements

DRAWING

1

REF:
PROJECT NO: ----
DATE:
CAD DWG FILE: PAVEMENTS - CON.DWG
DRAWN BY: ####
CHK'D BY: ####

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Appendix F

Data Summary

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Sources	*Construction Submittal Data [3]*	*Field Data Collection*			*Construction Submittal Data [3]*					*NHDOT Magnet [4]*	*UNH Study [5]*
Airport	*Project*	*Pavement Core #*	*Paint Chip Sample #*	*Rust Staining*	*Year*	*Supplier - Plant*	*Source*	*Pavement Data Available*	*Paint Data Available*	*% Iron*	*SEM/EDS % Iron*
Keene	SBG-08-06-2009 (Reconstruct, Mark and Light Terminal Apron)	1,2	1,2	Yes	2009	W. Lebanon, NH	Mix Design Data N.A.	QA Density Tests	Paint (Franklin) and beads submittal data	6.9	1.0-17.14
	SBG-08-02-2008 (General Expansion of TWY A)	3,4,5	None	Yes	2008	W. Lebanon, NH	W. Lebanon, NH	Mix Design: P-401 Surface 3/4"; Pike Plant P720; 2009 Slurry Seal (Tarconite)	No data	10.1	Not tested
Claremont	SBG-02-03-2010 (TWY C West)	1,2	1,2,3,4,5,6	Yes	2010	W. Lebanon, NH	W. Lebanon, NH	Mix Design; Extraction Tests; P-401 Surface 3/4"; Pike Plant P720; QA Density Tests	No data	3.3	6.8-74.4
	SBG-02-01-2008 (TWY C East)	3,4	7,8,9	Yes	2008	W. Lebanon, NH	W. Lebanon, NH	Mix Design; Extraction Tests; P-401 Surface 3/4"; Pike Plant P720; QA Density Tests	No data	8.2	
	3-33-0002-16-2005 (Construct 6 unit Hangar building and TWY B)	5	None	Yes	2006	W. Lebanon, NH	Mix Design Data N.A.	Extractions	No data	13.4	Not tested
Whitefield	SBG-17-03-2010 (Reconstruct Aircraft Terminal Ramp)	None	None	Surface Seal[2]	2011	Londonderry, NH	Londonderry & Bow, NH	CPI Mix Design (Londonderry, NH & Bow, NH Aggregates); Extractions	No data	Not tested	Not tested
	3-33-0017-15-2007 (TWY and Portion of Terminal Ramp)	1,2	1,2,3,4,5	Yes	2007	Gorham, NH	Milan NH & Gilead ME	Pike Mix Design (Milan NH, Gilead, ME); Extraction	Paint (Sherwin Williams) submittal data	5.5	5.3-73.4
	3-33-0017-13-2005 (RWY 10-28)	3,4	6,7,8,9,10	Yes	2006	Gorham, NH	Gorham, NH	Pike Mix Design (Gorham, NH); Extraction	No data	7.0	
Laconia	SGB-09-03-2009 (Terminal Apron)	None	None	Surface Seal[2]	2009	Londonderry, NH	Bow, NH	Mix Design; Extractions	Paint (Sherwin)	Not tested	Not tested
	SBG-09-02-2009 (TWY C)	3,4	9,10	Yes	2009	Northfield, NH	Belmont & Hooksett, NH	Mix Design; Extractions	No data	1.0	0.7-74.1
	3-33-0009-16-2005 (RWY 8-26 & TWY B)	1,2	1,2,3,4,5,6,7,8	Yes	2006	Northfield, NH	Belmont, NH	Mix Design; Extractions	No data	2.9	
	3-33-0009-17-2007 (Itinerant Apron Phase 2)	None	None	Surface Seal[2]	2007	Northfield, NH	Belmont, NH	Mix Design	No data	Not tested	Not tested
	3-33-0009-15-2004 (Itinerant Apron Phase 1)	None	None	Surface Seal[2]	2004	Northfield, NH	Mix Design Data N.A.	Extractions	No data	Not tested	Not tested
Concord	3-33-0004-15-2002 (RWY 12-30)	1,2	1,2	Yes	2003	Londonderry, NH	Mix Design Data N.A.	Extractions	No data	0.5	4.2-15.9

Notes:
1. Acronymns: TWY - Taxiway; RWY - Runway; FA - fine aggregate; CA - course aggregate; N.A.- Not Available.
2. Surface Seal - Asphalt sealant applied to pavement surface. Sealant maybe concealing rust staining.
3. Construction submittal data provided by NHDOT. A summary of the data is provided in Appendix E.
4. NHDOT Magnet: Refers to percentage of Ferrous Material in Sample Portion Passing #4 Sieve. See Appendix C for referenced core number and values.
5. Values are the percent iron content on paint chips measured by the SEM/EDS. Refer to Appendix D.

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Appendix G

Agency and Industry Telephone Interviews

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CONTACT	MIKE SPEIDEL
ORGANIZATION/COMPANY	SIGHTLINE AMC
ADDRESS	15483 ENTERPRISE WAY, CULPEPER, VA 22701
EMAIL	CONTACTUS@SIGHTLINE.US; MIKE@SIGHTLINE.US
WEBSITE	NOT PROVIDED
PHONE NUMBER(S)	(540) 825-9660; CELL: (540) 272-3583
NOTES	
Aware of the problem - they were involved in the creation of IPRF Airfield Marking Handbook.	
They saw rust staining first in Maryland, Packs River Naval Air Station. At first they just kept repainting every year but the staining just bled through.	
They recommend paint that was developed by Chuck Carneal of Safety Coatings. Mike says he is very outgoing extremely bright – in Foley Alabama – Sightline has strong relationship with him.	
Cause - Not sure of exact terms but an iron derivative in the aggregate transfers through the oils of the pavement coming to the surface, carrying iron particles, rain hits crown of road surface and runs off to sides. Rust staining usually worse at leading edge. Referred to handbook examples.	
The resistant paint is slightly off from the Federal TT-P-1952 spec. He feels it is a much better paint.	
Not sure of specifics but the formulation is varied slightly such that it is resin rich with changes in the amounts of solids and pigment such that some of the values are slightly off from the 1952E spec. (refers to Chuck Corneal for knowing the details)	
Type I and II are very similar except for the dry time, type II has a faster dry time. It has a fast track resin developed by Rohm & Haus now owned by Dow Chemical. 10 minutes vs. 2-3 minutes.	
Type III was made to be similar to a preformed thermoplastic product that was more durable, a 60mil thick marking (beads embedded throughout paint). Type III can be applied up to 30 wet mils and has a cross-linking resin the gives it more flexibility. Type III also gives more flexibility on striping geometry and size as opposed to preformed thermoplastics.	
Beads in both types give frictional characteristics so the marking is not too slippery.	
Their saying is that if you have been to one airport, you have been to one airport! All airports are different. They see quality differences all over the map, even within the same state.	
The rust resistant paint can be formulated for Type I, II or III paints.	
Glass beads are Type I, III and IV (grade A and B).	
There is a distinct difference between Type I and II beads for cost and quality. Type I is for standard highway use. It is cheaper and if you paint every year it is ok to use.	
Type II is no longer used. Type IV are the largest, grades A and B. Type III beads are 20% larger than type I, have high index of refraction (IOR).	
With the proper surface preparation, paint and bead application, Type III beads can last 5+ years.	
Sightline does training courses throughout the country.	
If you spend more up front, the pilot distance recognition of Type III is better. Think of a mag-lite flashlight. A large diameter diffuse beam would be Type I beads whereas a tightly focused small beam would be Type III. Distance of visibility should be 1000 feet.	
They have seen rust staining in Maryland, North Carolina, Georgia, and Seattle (pretty much all over the country).	
They do audits and consulting. They are there to improve quality control. Unfortunately many airports are slave to low bidder. Usually an RFP is sent out and the lowest bidder gets the job.	
There are no qualifications set by FAA. Even with regard to the type of equipment used. A striper can use a truck without a beader and then go and throw beads on by hand afterwards. They have seen water added to paint to make it more spreadable.	

They are doing an audit in L.A. (more like a maintenance evaluation) trying to figure out why they don't have glass beads embedded on a paint with 30-40 mil thickness.
Numerous times they have seen projects, like design-build, that may take two years to complete yet the painting has to be done in 3 nights/days with a deadline. They say it is like a flea on the tail of a dog.
They review the individual needs of each airport. A New Hampshire statewide spec may not be adequate for every airport.
They have a trusted Agent program.
They are involved in sending out RFP's with specific criteria, evaluating bids that come back and awarding the one with the greatest assurance for quality.
They can either supervise an entire job or work with them on getting started, checking calibrations, etc.
They provide an aluminum test coupon. 9 out of 10 times the trucks are set at speeds twice as fast as they should be. They evaluate both thickness and uniformity of thickness profile across the width of the line. This is important. They try to ensure quality of product for future performance.
They do statewide audits and maintenance evaluations. Are working to set up something with Florida Department of Transportation.
Mike thinks that a rust resistant Type III paint with Type III beads is the best combination.
Companies well known in proximity of region are Safety Markings and Hi-Lites.
Look at airports to determine what work needs to be done for preparing surface. If asphalt is distressed, just putting paint on won't work. Determine if prior paint needs to be cleaned, blasted or removed.
They tried using a sealant (glass coating 1 mil thick) to seal markings as they are water permeable. The markings were easier to clean and resisted fading, however, the reflectivity of the beads was reduced by 50%.

CONTACT	BETSY HUDSON
ORGANIZATION/COMPANY	PAVEMENT MARKING SOLUTIONS
ADDRESS	WALKER ROAD, BARNHART, MISSOURI 63012
EMAIL	BETSY@PAVEMENTMARKINGSOLUTIONS.COM
WEBSITE	HTTP://PAVEMENTMARKINGSOLUTIONS.COM
PHONE NUMBER(S)	(636) 373-1926

NOTES
Betsy established the company in 2010. She originally started Sightline with Donna Speidel.
She is aware of modified paint from Safety Coatings. She thinks the modified paint would help both top surface staining and leaching from underneath. It won't get rid of the problem but last longer than the standard paint. The pigment has a finer grind which makes the paint less porous.
Had a job in North Carolina and Florida where algae was a problem. Not sure of exact cost but believes it is 1.5 to 2 times more expensive per gallon.
A procedure of putting 7 mils down first as a primer has been done for new asphalt. After drying, an additional 15 mil coat with glass beads is put down. This is mentioned in P620.
They have done testing on panels in salt fog cabinets and/or humidity cabinets with coated steel panels having a scribed x.
She was involved with the Protective Coating Industry and mentioned NTPEP.
Is aware of aluminum tape that is used (FOL) and a primer is put down first but thinks it is probably an adhesive.
She works with FOL tape and she was a previous employee of Flex-o-lite(glass bead company)that was bought out by Potters.
She had worked on the Atlanta Hartsfield Airport doing reflectometer readings with Mike Speidel when she was still part of Sightline. At the time she did over 2000 measurements and he took 200 photographs.
They have worked on using part (a) and part (b) coatings for this airport .
Does not recommend using Methylmethacrylate because it is very brittle and tends to damage pavement surface itself. It won't come off easily even with 40 to 50 ksi water blasting.
The thermoplastics get sheared off with snowplowing.
She has also seen pavement problems with waterborne paint that is put down too thick.
In Michigan there has been police in the wooded area with radar guns clocking striping trucks at 18-20 mph.
They have had issues with the quality of Type III high index glass beads. They are 7-10X brighter than the recycled glass. They have found that the cheaper recycled beads have been mixed and put into Type III bags.
A contractor in Florida got a bundled painting/cleaning package for 32 of their airports. He had a hand liner and was not equipped or qualified to do those jobs.
They have found that 80% of the airports surveyed (15 total) were deficient in markings.
They held classes with 30 maintenance personnel from each quadrant going through best practices, testing for moisture, coverage rates, etc.
There was a case in Lexington Kentucky where there was an airport under construction that did their own markings. The accident occurred due to inconspicuous markings. They were hired to go over runway painting techniques.
There was a case where a plane took off and markings were still wet. Paint was noticed on the nose when it landed. The nose gear had paint on it and they found glass beads on the intake valve. The life of the engine was compromised. Pratt Whitney was involved and the overall settlement was $42 million as

other planes had similar issues.
Innovative Pavement Research Foundation – Airfield Marking Handbook
Texas Transportation Institute – Gene Hawkin. Involved with a lot of research
High pressure water blaster also removes rubber and paint buildup.

CONTACT	HERMAN IRANI (CHEMIST)
ORGANIZATION/COMPANY	U.S. SPECIALTY COATINGS
ADDRESS	HEADQUARTERS IN GA
EMAIL	NOT PROVIDED
WEBSITE	NOT PROVIDED
PHONE NUMBER(S)	(800) 278-7473
NOTES	
To solve staining from aggregate underneath leaching into paint – need to use a solvent base clear coat first – does not know of a product currently available – they would be able to develop one so that waterborne paint on top would adhere to clear coat.	
To solve staining from sheet flow on top - need to use a clear coat but would be concerned about loss of friction and could affect retro-reflectivity of beads – again it would have to be developed.	
They are working on a luminescent paint –clear, however it tends to make white slightly amber. The luminescent paint does not need light to show up like retro-reflective beads. It collects light during the daylight and then luminesces the light at night. Have not tried it yet on an airport runway. Have used it on railings, traffic paint, etc. Still being developed.	
They provide many other products for other markings at the airport. Have many colors of paints (water based and solvent based) and polyurethane clear coat in aerosol cans, stencils, etc.	

CONTACT	CHUCK CARNEAL
ORGANIZATION/COMPANY	SAFETY COATINGS
ADDRESS	20180 SAFETY LANE
EMAIL	CCARNEAL@SAFETYCOATINGS.COM
WEBSITE	NOT PROVIDED
PHONE NUMBER(S)	(800) 557-8810 (251) 943-1638
NOTES	

Chuck was involved in creating a modified 1952E paint to help a rust stain problem in Maryland. Since then it has been used on 4 to 5 other jobs with great success.
The work was done in conjunction with Sightline Construction to solve the issue.
Believed the source was from iron deposits within the soil that would wash across the lines creating the staining.
Donna Speidel asked Safety Coatings to develop a product that would prevent that. Chuck worked with Dow, however, they did not know how he was using the resin.
There also was an airport site that had issues with algae staining so they incorporated an algaecide into the paint as well. It is stain resistant as well mildew resistant.
The paint does not meet TT-P-1952E. They called it “modified”. The only difference from the federal spec is that the pigment is lower, around 40% compared to 60-62%. The airports that used it got a variance form the FAA.
The modification resulted in a different resin/pigment ratio with all other properties of the spec remaining the same.
He said this was designed solely for top surface staining and did not know how it would perform for staining leaching through the bottom surface of the paint. He could send a sample for us to test.
I asked if they tried sealers underneath the paint and he said no. The problem with sealers is that they produce a gloss impenetrable surface that bonding to other coatings is an issue. Doesn’t know of any sealers that might work with the paint. Suggested that if the paint has the ability to resist staining on the top surface that it might work for bottom surface leaching as well.
They do not use any chlorinated rubber paint anymore because the resins can’t be manufactured here in the states due to environmental and health issues. Very few companies use it that he knows of.
They use a 100% solvent based acrylic called plastibar for cold weather applications. There is another type called Plastimark which is cheaper for shorter term applications. It is only 75% as durable however, 70% of the cost.
They are a small company of 16 employees that like to have fun and solve customer problems. This is why they like working with Donna Speidel.
He mentioned that he has been told there is approximately 100 million gallons of paint used per year in the states. There are 6 to 7 manufacturers. They make barely one percent. Ennis and Sherwin-Williams have bought up most of the smaller companies and there are only about 4 to 5 little companies left. He used to work for Baltimore paint years ago. Mentioned they are now owned by Sherwin-Williams as well.
They can make paint in batches of 5000 gallons.
Asked about their experience with TiO_2. He says that they have had some dispersion issues. If the particle size is not as fine the TiO_2 opacity will not be as high even with the same amount present. They have had same product, same company and for some reason the grind is not the same to create dispersion problems. Need finer grind.

CONTACT	GREG CLINE
ORGANIZATION/COMPANY	FAA TECHNICAL CENTER
ADDRESS	FAA – WASHINGTON DC HEADQUARTERS
EMAIL	GREGORY.CLINE@FAA.GOV
WEBSITE	NOT APPLICABLE
PHONE NUMBER(S)	(202) 267-8814
NOTES	
Is familiar with the problem – comes up several times a year.	
Does not know of a way to solve the problem other than not having iron in the aggregate.	
He is more of a policy person rather than technical – is referring Holly Cyrus and will provide number and e-mail. She is at the Atlantic City location at the Tech Center.	
Airports can use whatever they would like if they aren't federally funded. If they use federal funds for the job then it has to be from the federal spec.	
Sometimes a large freight company such as UPS will pay to have whatever material they would like. e.g. thermoplastic.	
Does think issue is more severe with waterborne paint although yellowing of paint has always occurred.	
We do not use luminescent paints in the states. Europe has tried it in a couple of places but only recently within the last couple of years.	
Once every four years there is a tech transfer conference – this year it will be in Atlantic City. Friction requirements must still be acquired with whatever material is used.	

CONTACT	HOLLY CYRUS
ORGANIZATION/COMPANY	WILLIAM J. HUGHES FAA TECHNICAL CENTER
ADDRESS	FAA ATLANTIC CITY, NJ
EMAIL	NOT PROVIDED
WEBSITE	NA
PHONE NUMBER(S)	(609) 485-4887
NOTES	
Given her name from Greg Cline	
She is involved in field testing of different airport marking products and conditions.	
She is with the safety side. There is also a pavement side which has a number of engineers.	
They have been successful with a light water buffing with added bleach to remove rust colored stained areas.	
They tried using an "Adsil glass coating" product to seal the lines but retro was reduced 40%.	
When doing rubber removal all beads will be removed from the high pressure water required. Pressure used to remove staining is less.	
Have tried sealants previously but have had bonding issues where paint would peel off. Found that they needed a 30 day dry time on some of the sealants before markings could be put down.	
Working with methylmethacrylate right now. Staining occurs with that type of coating as well. She says that it occurs with all of the coatings.	
Waterborne is used 99% of the time on the runways themselves.	
Thermoplastics are good for other areas of the airport. Have found glue which makes them stay in place better – not for use on runways.	
Worked with Jeff Rapol who is retired now.	
Gave me the name of Cindy Randazzo who works for Rhom & Haas : (215) 641-7750 crandazzo@rhomhaas.com *(*have not contacted yet)*	
Also gave me the link to the FAA reports www.airport.tc.faa.gov. which has a Paint and Bead Durability Study. Several paint manufacturers and bead types were evaluated for best performance.	

CONTACT	ANTHONY COCHRAN
ORGANIZATION/COMPANY	FAA DISTRICT OFFICE – SOUTHERN REGION
ADDRESS	
EMAIL	ANTHONY.COCHRAN@FAA.GOV
WEBSITE	
PHONE NUMBER(S)	(404) 305-6713
NOTES	
Originally contacted Nick Goodly from the Atlanta GA office and he said to speak with Anthony Cochran who is the Regional Head for the Southern Region.	
Anthony said it was interesting that I call about this subject because the state of Georgia called one month ago about the P-620 spec and wanted to add a microbiocide to their paint due to algae growth and mildew issues from extreme humidity conditions along the coast. North Carolina is already doing this.	
He used to be in charge of the office for GA, N. Carolina and S. Carolina.	
S. Carolina had issues with iron deposits coming up through and staining the paint. He said I should talk to the maintenance engineer in S. Carolina to find out the details and how the problem was solved.	
Jamey Kempson (803) 896-6291. (*have not contacted yet)*	
He also said to send him an e-mail and he will distribute it to their lead certification inspector and some of their engineers for input.	

CONTACT	JOHN MERCK
ORGANIZATION/COMPANY	FAA NE DISTRICT OFFICE - CT, ME, MA, NH, RI, AND VT
ADDRESS	LOCATED IN BURLINGTON, MA
EMAIL	
WEBSITE	
PHONE NUMBER(S)	(781) 238-7623
NOTES	
Aware of problem but not really involved with solutions.	
Involved with new paint grant assurances and then it is the state's responsibility to maintain markings.	
Not sure of process required to have manufacturers come up with modified paint and get blessing of FAA when it doesn't fit within FAA spec.	
Asked about whether or not grooving under the markings would be acceptable so that a high build and better bead package could be used and would resist plow damage. He said that is not allowed in the current spec.	
He works with Barry Hammer and recommended that I talk with him to see if he might have any personal experience which could add more information.	
He said Greg Kline of the FAA Technical Center would be good to contact.	

CONTACT	NATE HATLEBACK, PAUL JOHNSON
ORGANIZATION/COMPANY	FAA DISTRICT OFFICE, N.W. REGION
ADDRESS	
EMAIL	
WEBSITE	
PHONE NUMBER(S)	(303) 342-1280
NOTES	
He is in Utah and his office covers CO, UT, WY	
He doesn't think they have that kind of problem there. They have issues with a lot of sunshine and snow removal.	
Crack seal and sealcoating usually happens every 4-5 years and states restripe every few years.	
Restriping is usually done often enough where that problem has not occurred.	
He recommended that I talk with Paul Johnson who is the Engineer / Pavement Specialist for the N.W. Region	
Notes with Paul Johnson Engineer / Pavement Specialist for N.W. Mountain Region	
(425) 227-2622	
He has heard of the problem. They usually have to paint every 1-2 years and they have not had a significant problem with it.	
He says that modifications needed to a certain specification have to go through Washington and then the Tech Center in New Jersey is usually involved in testing before approval and changes to the spec.	
He did say that in the meantime, however, if there is an airport with a specific problem like this they would grant a temporary modification to the standard.	
Current specs do not allow for any recessed grooving of the paint. If it was needed in certain locations and hydroplaning is not an issue it could be approved.	

CONTACT	TOM MAHONEY, CLIFF VACIRCA
ORGANIZATION/COMPANY	
ADDRESS	
EMAIL	
WEBSITE	
PHONE NUMBER(S)	(617) 412-3689 (WAS TRANSFERRED TO HIM)
NOTES	

They are familiar with this problem but only on aiming points where there is a large surface area covered with white paint.
They found discoloration was closer to the centerline vs. the edge line.
They painted all 32 airports 1 year ago. Did not create any new lines, basically gave all old lines a fresh coat. They got a lump sum price per airport.
Used the same contractor. Did a good job for the most part. Had an engineer on site the entire time for supervision. Insisted that the contractor had experience with airports.
Used standard federal spec paint and on some of the airports they required type III bead package. Most airports used type II. (*not available anymore)*
Recommended I talk with Cliff Vacirca who is FAA representative in Burlington, MA.
Notes from Cliff Vacirca, FAA New England Region
(781) 238-7627
They experience the same thing.
See it mostly on the edge lines as sheet flow travels across width of runway.
He also sees it on the roads and thinks that tire action on the paint may rub some of it off.
They do not seal coat the runway. They have grooved sections of runway for friction.
He thinks the FAA Tech Center may have done research studies jointly with TRB.
He knows of Greg Cline who took over Jeff Rapol's position when he retired. He thinks there was a pavement yellowing test.
Does not know of using anything else on the actual runways other than waterborne. Thinks this problem is more prevalent with the waterborne as opposed to the oil based paints years ago.
Different paints like thermoplastic are used on small sections like hold bars. Waterborne is used on edge lines, touchdown zones and aiming points. These areas are huge in surface area compared to other airport markings. Some edge stripes are 3 ft. wide and aiming points are 150 ft. long with width depending on runway width.

CONTACT	JOHN SCHROEDER
ORGANIZATION/COMPANY	MINN DOT
ADDRESS	
EMAIL	JOHN.SCHROEDER@STATE.MN.US
WEBSITE	
PHONE NUMBER(S)	
NOTES	
They use the same paint as their roads, waterborne.	
They had a demonstration given to them last summer – by the people who were associated with the airport Markings Handbook.	
They do not really see this problem in their state. They use primarily SherwinWilliams paint - apply 10-15ml wet.	
Use Potters beads, not sure which type. He thinks the same as the roads, Type **I**, possibly Type **III** in some areas.	
They have significant iron in their aggregate but do not have a rust staining issue.	
They use striated painting, six inches between every line to increase performance as opposed to block painting.	
They use a slurry seal over their asphalt. Sometimes if it is applied over newer paint the adhesion is not that good and it will scrape off in the winter from the snowplows.	
He is going to check into which type of slurry seal they use.	
I sent him my e-mail and he said he would try to find out more information and send it to me.	

CONTACT	ROBIN SUKLEY
ORGANIZATION/COMPANY	PENN DOT
ADDRESS	
EMAIL	RSUKLEY@PA.GOV
WEBSITE	
PHONE NUMBER(S)	(717) 705-1250
NOTES	
He said that FAA is in charge of commercial airports. They have not seen this problem on the GA airports for which they are involved.	
They use aggregate from W. Virginia and some from New York as well. They have a lot of limestone, some granite. He is going to get information on their high friction value aggregate and send it to me once I send him an e-mail.	
Robin is division chief of engineering and planning.	
Robin contacted the aviation Project managers across the state of PA for information. Occasionally they have seen some problems when slag is used in the bituminous wearing surface. Waterborne paints do not last very long and as a best practice they have bundled several GA airports to crack seal and restripe to gain economies of scale.	

CONTACT	TIM LESIEGE
ORGANIZATION/COMPANY	ME DOT
ADDRESS	
EMAIL	
WEBSITE	
PHONE NUMBER(S)	(207) 624-3249
NOTES	
They do have the problem.	
They are not aware of any solution.	
They just repaint when the FAA tells them it has to be done.	
They have not identified the underlying problem causing the issue.	

CONTACT	DAVE VILLANI
ORGANIZATION/COMPANY	ENNIS FLINT
ADDRESS	NOT PROVIDED
EMAIL	DAVEV@ENNISTRAFFIC.COM
WEBSITE	WWW.ENNISFLINT.COM
PHONE NUMBER(S)	(678) 558-1660

NOTES
They have paints with a stain and moisture resistant additive. He will send the product brochure. It is not on the website.
The paints still fall within the Federal spec TT-P-1952E. They have Type II and Type III paints. Type II is fast track, quick drying and Type III is hi-build with Rohm & Haas HD21 resin. If you are going to use big beads your wet film thickness should be 20-25 mils.
There were a few airports in North and South Carolina where these paints were first tried.
The mildew staining problem seems to be more prevalent with water base paint. The water based thickeners are “better stuff to eat” as Dave says (as far as mold is concerned).
They also have thermoplastics but can only be used as preform thermoplastics on taxi ways – never on the runway.
They also carry epoxy but it is not generally used. It is more expensive than the waterborne. Many times the bigger airports are consistently cleaning the rubber off the runway and it removes the paint as well so they don’t use something more expensive.
Best practice for restriping over stained markings is to remove old markings and put down with new.

CONTACT	CHRIS FOX
ORGANIZATION/COMPANY	SHERWIN WILLIAMS
ADDRESS	NOT PROVIDED
EMAIL	NOT PROVIDED
WEBSITE	NOT PROVIDED
PHONE NUMBER(S)	(216) 515-5585 OFFICE (216) 386-7271 MOBILE

NOTES
They have been working on a 1952E Type III paint and adding a rust inhibitor. It has been applied to steel panels and have not seen flash rusting. It has a proven history as an additive and has been used in architectural products that go on steel.
There have already been batches made and used with algae inhibitor. They will put both algae and rust inhibitor in the Type III paint. Inhibitors have been successfully added without creating issues to other properties.
The 1952E requires a high pigment of 60-62% and contains a lot of calcium carbonate which is susceptible to absorption. This makes it susceptible to staining from sheet flow.
Nebraska was using a FPO3 (Federal LANS?) specification is not for airports but an application requiring more resin. The spec allows 45-55% pigment. Maybe this spec could be looked at and used instead of the 1952E as it is still a federal spec.
They have not tried using any primer or sealant underneath the paint marking.
They have looked into methylmethacrylate but it is not approved for FAA runway applications.
Does not know of any inlaid applications used on airports. They just put down on a Nettpep test deck this year an inlaid section both on concrete and asphalt. It is expensive because a normal application of the paint you want in an inlay has to be put on the test deck by itself as well. The cost is about $4300.00 for the normal test and an additional $2300.00 for the inlay. They put down waterborne and MMA in grooves.
Test decks are tough because in 2012 there was a huge amount of snow and it was plowed 700 times. Of course, the paint was worn off.
In Minnesota they did a high friction deck covering a full lane for 200 ft. put down 60 mils and put aggregate into it. MMA works well with transverse legends and markings.
Most traffic paint made and used on the roads today would classify as a type II on the TT-P-1952E federal spec.
For Type III they want the drying characteristics of Type I and specific IR peaks defined in the spec and 100% cross-linking i.e. HD21. Pretty much requires the use of patented material from Rohm and Haas.

CONTACT	DAN MARCET
ORGANIZATION/COMPANY	FRANKLIN PAINT
ADDRESS	NOT PROVIDED
EMAIL	NOT PROVIDED
WEBSITE	NOT PROVIDED
PHONE NUMBER(S)	NOT PROVIDED
NOTES	
Franklin paint makes TT-P-1952E and uses it for both traffic road paint and airport paint.	
They do not have a special formula for airports but would be willing to work on.	

CONTACT	DAVE VILLANI
ORGANIZATION/COMPANY	EPOXY – ENNIS FLINT
ADDRESS	NOT PROVIDED
EMAIL	NOT PROVIDED
WEBSITE	NOT PROVIDED
PHONE NUMBER(S)	NOT PROVIDED
NOTES	
They make epoxy paint for airport applications but it is rarely used for runway markings.	

CONTACT	DEE WATKINS
ORGANIZATION/COMPANY	TAPE – FOL TAPE
ADDRESS	NOT PROVIDED
EMAIL	NOT PROVIDED
WEBSITE	NOT PROVIDED
PHONE NUMBER(S)	(888) 365-8273

NOTES
Stock of tape is typically in 4in. widths. Could go up to 12 inches. Usually comes in 50 yd. or 100 yd. lengths.
Estimated ball park price: example 6” X 50yds is $74.00 for the roll.
They have supplied to airports previously, not sure for what application.
The wet reflective tape has 1.9 hi-index beads.
The tape is temporary or removable. It will disintegrate with high heat. Can be removed by applying some heat and peeling away from surface.
Water blasting can also be used but fragments of aluminum will still be left behind. Asked about skid resistance and she said it has minimum resistance of 45 BPN when tested according to ASTM E303. Their tape is used for roads and falls under spec ASTM D4592.
They have a test deck outside their facility. Does not have much traffic and has lasted at least one year. Not sure of application where airplane tires would be landing on it since it is susceptible to heat deterioration. She does not know the location on the airports where it has been purchased in the past.
She is going to check with others within the company if they are familiar with an FAA rep that they may have worked with in the past.
Dee is going to send sample anyway, but other person in their company said this tape absolutely cannot be used on runways where the planes are. Any turning, degradation or peeling of the tape will result in FOD.

CONTACT	STACY COLE
ORGANIZATION/COMPANY	TAPE – COLE BROTHERS
ADDRESS	NOT PROVIDED
EMAIL	NOT PROVIDED
WEBSITE	NOT PROVIDED
PHONE NUMBER(S)	(850) 934-3157
NOTES	
Recommends talking with a thermoplastic manufacturer (Ennis Flint).	
Thermoplastic melts into the asphalt creating molecular bonds in the pores.	
Not sure how iron rich minerals in aggregate would affect the bonding and adhesion.	
Steve (unknown lasts name) believes the discoloration is coming up when the paint is wet and will draw up through the substrate.	
Thermoplastic is molten for a short time in comparison and therefore may not be as susceptible to discoloration.	
Is not that involved in the details and really recommends talking with Ennis Flint. Flint does have on their website airport and military applications.	

CONTACT	KEVIN HALL
ORGANIZATION/COMPANY	BEADS – POTTERS INDUSTRIES
ADDRESS	NOT PROVIDED
EMAIL	NOT PROVIDED
WEBSITE	NOT PROVIDED
PHONE NUMBER(S)	(800) 552-3237
NOTES	
Kevin Hall is their contact for glass beads on airports.	
They are familiar with the problem.	
They incorporate paint with glass beads to solve the issue.	
They use rust inhibitors if you aren't going to seal.	
It appears they have connection with Safety Coatings. They are going to send brochure of their products.	
They have two bead packages, Type I, usually used with FAA paint Type I and II and Type III beads usually used with Type III (high performance) paint. It has a higher resin content and better quality TiO2.	
They would bundle together, provide guarantee of initial retro performance – training, retro, testing of retro.	
No coating is put on beads themselves.	
They can formulate paint to be both UV and rust resistant.	
Retro reflectivity is a system – it requires paint and beads.	
Don't want paint layers to become too thick on runways because it will flake off as FOD.	
Must use federal formulations and bead products if using federal funding. Otherwise it doesn't matter.	

CONTACT	BILL GANGER
ORGANIZATION/COMPANY	STAR SEAL
ADDRESS	NOT PROVIDED
EMAIL	B.GANGER@STARTSEAL.COM
WEBSITE	NOT PROVIDED
PHONE NUMBER(S)	(800) 759-1912
NOTES	
He is marketing and business development person.	
They are very familiar with this problem.	
They just recently did an airport in San Francisco. There was a high pyrite content in their aggregate creating thumb sized rust spots all over the runway.	
Their solution is two part. 1) First lay down a coating of “Rust Arrest” using a normal spray truck – do one coat application. 2) Apply one, possibly two (especially first time) of “Start Seal Aviator” – this is an FAA approved certified rubber product.	
This is a maintenance treatment – recommends this two part treatment at first, after 4 years an additional coat of the Star Seal Aviator should be applied with striping.	
Many paints have solvents which need to be tested with the coating for compatibility. Some paints eat thru the coating.	
Test project should include large enough area. Can stripe within a couple of hours of coating or minutes – make sure there is no issue of solvents coming through. – They do use Sherwin Williams paint and sell it as well.	
15 plants make seal coating within the US. The closest plant is Harrisburg PA. Different plants use different paint manufacturers depending on area, preferences, etc. The technical representative is Mr. Dubey	
Two options considered in solving the staining issue: 1) Outline in black the pavement runway marking and apply stripe over – this won’t help sheet flow. 2) Seal the entire runway – not only good for sheet flow but also runway pavement longevity. As pyrite oxidizes, forms bump and explodes, more and more water is absorbed into pavement attacking sub base. Cracking and eventually potholes occur.	
They have seen this problem on relatively new runways.	
If you have 5 to 6 years in a 20 yr. old runway and have been struggling with this problem, you can spend $125,000 and paint every couple of years, spend $2.5 million for slurry seal, spend $10 million to repave or $44,000 every 3-5 years of seal coating and paint will remain true color during that time. These are just relative comparison numbers.	
The coating treatment adds only 0.036 inches of thickness.	
They would be willing to come out and do test section. Need a couple of good sunny days with temperatures into the 60’s.	
He is going to send technical information of the products.	

CONTACT	JAMIE DAVIS
ORGANIZATION/COMPANY	NEW ENGLAND SEAL COATING
ADDRESS	NOT PROVIDED
EMAIL	NOT PROVIDED
WEBSITE	NOT PROVIDED
PHONE NUMBER(S)	(603) 217-7233
NOTES	
He is son of family business, Davis & Swanson that started in 1983.	
They used to apply heavy sand slurry coats for taxiways at airports, P-625 spec.	
Highway traffic usually has 3lbs vs. their heavy mix of 4-6 lbs. Airports use greater than 6 lbs. Additives have to be used so that the excess amount of sand stays in suspension and there is an even dispersion of the sand. A high solids content is required.	
Mentioned about oil base vs. waterbase. The oil base paint on asphalt deteriorates the asphalt from the oils.	
He is going to check with an associate in the industry if there are any primer type sealcoats that could be used and call back with the information.	
Jamie Davis called back and said the expert he contacted will get back to him. He is from Industrial Traffic Lines and is at a conference in Texas, a striping/safety show.	

Appendix H

Life-cycle Cost Analyses

Discount Rate =	3%		Present Value ($) Required for Future Work[4]																			20 Year Present Value[5]
Year	Units[2]	Initial Year Costs[3]	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	SF Cost[6]
Type I/II Paint with Type I Beads																						
Paint & Beads	SF	$ 1.33	$ 1.33	$ 1.22	$ 1.18	$ 1.15	$ 1.11	$ 1.08	$ 1.05	$ 1.02	$ 0.99	$ 0.96	$ 0.93	$ 0.91	$ 0.88	$ 0.85	$ 0.83	$ 0.80	$ 0.78	$ 0.76	$ 0.74	$ 19.90
Removal	SF	$ 1.69	$ 1.59		$ 1.50		$ 1.42		$ 1.33		$ 1.26		$ 1.19		$ 1.12		$ 1.05		$ 0.99		$ 0.94	$ 12.39
																						$ 32.29
Modified Type I/II Paint with Type I Beads																						
Mod. Paint & Beads	SF	$ 1.36	$ 1.28	$ 1.24	$ 1.21	$ 1.17	$ 1.14	$ 1.11	$ 1.07	$ 1.04	$ 1.01	$ 0.98	$ 0.95	$ 0.93	$ 0.90	$ 0.87	$ 0.85	$ 0.82	$ 0.80	$ 0.78	$ 0.75	$ 20.27
Removal	SF	$ 1.69	$ 1.59		$ 1.50		$ 1.42		$ 1.33		$ 1.26		$ 1.19		$ 1.12		$ 1.05		$ 0.99		$ 0.94	$ 12.39
																						$ 32.66
Type III Paint with Type III Beads																						
Paint & Beads	SF	$ 1.60	No Activity This Year	$ 1.46	No Activity This Year	$ 1.38	No Activity This Year	$ 1.30	No Activity This Year	$ 1.23	No Activity This Year	$ 1.16	No Activity This Year	$ 1.09	No Activity This Year	$ 1.03	No Activity This Year	$ 0.97	No Activity This Year	$ 0.91	No Activity This Year	$ 12.12
Removal	SF	$ 1.69				$ 1.46				$ 1.30				$ 1.15				$ 1.02				$ 4.93
																						$ 17.05
Modified Type III Paint with Type III Beads																						
Mod. Paint & Beads	SF	$ 1.63	No Activity This Year		No Activity This Year	$ 1.41	No Activity This Year		No Activity This Year	$ 1.25	No Activity This Year		No Activity This Year	$ 1.11	No Activity This Year		No Activity This Year	$ 0.99	No Activity This Year		No Activity This Year	$ 6.38
Washing	SF	$ 0.36		$ 0.33				$ 0.29				$ 0.26				$ 0.23				$ 0.21		$ 1.32
Removal	SF	$ 1.69								$ 1.30				$ 1.15								$ 2.45
																						$ 10.15

Notes:
1. Present value is the current worth of a future sum of money given a specified rate of return. Discount rate is the rate of return on invested money. Refer to the attached Present Value Notes.
2. Unit Acronymn: SF - Square Feet
3. Initial costs based on 2014 construction costs estimate, correspondence with the material manufacturers and engineer's estimate.
4. Refer to Present Value notes for the present value calculation.
5. 20 Year Present Value is the sum of present values over the 20 year study period. The lowest value is preferred. Values should be used for comparison purposes.
6. Washing and/or removal costs are mathematically summed into the 20 year costs after the initial year.

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Present Value Notes

I. Unit Costs:

Costs are based on 2014 bid price values, discussions with manufacturers and engineering estimates. The calculation of the estimated cost is noted below.

Project	Year Bid	# of Bidders	Type I/II Paint with Type I Beads Average Installed Costs $/SF
Skyhaven Runway	2014	7	$1.41
Concord Taxiway B Phase 2/3	2014	5	$1.32
Concord Taxiway B Phase 1	2013	7	$1.27
Type I/II with Type I Beads - Average $/SF			$1.33

Manufacturers Costs/Life (reference Chuck Carneal @ Safety Coatings, Inc. October 2014)

Paint and Bead Combinations	Manufacturer's Material Costs $/SF	Life (Years)
Type I/II Paint with Type I Beads	$0.140	1-2*
Type I/II Paint	$0.106	
Modified Type I/II paint with Type I Beads	$0.166	2-3*
Modified Type I/II paint	$0.132	
Modified Type III paint with Type III beads	$0.435	4-5
Modified Type III paint	$0.165	

*Note FAA P-620 allows the use of Type I beads when painting every 6 months.

Installed Costs Determinations

- Type I/II Paint with Type I Beads: $1.33/SF (see table above)
- Manufacture's Cost to Modify the Paint:
  - Mfg. Modified Type I/II Paint $0.132/SF - Mfg. Type I/II Paint $0.106/SF) = $0.026/SF (use $0.03/SF)
- Modified Type I/II paint with Type I Beads Installed Costs:
  - $1.33/SF + $0.03/SF = $1.36/SF
- Type I beads:
  - $0.140/SF - $0.106/SF=$0.034/SF
- Type III beads:
  - $0.435/SF-$0.165/SF = $0.27/SF
- Type III Paint and Type III Beads Installed Costs:
  - Modified Type I/II Paint with Type I Beads ($0.166/SF) ~ Modified Type III Paint ($0.165/SF). Therefore, use $1.36/SF (see above) as the unit cost base.
  - $1.36/SF - $0.03/SF (modifier)+ $0.27/SF (Type III beads) = $1.60/SF

- Modified Type III Paint and Type III Beads Installed Costs:
    - $1.60/SF + $0.03/SF (modifier) = $1.63/SF

Washing Paint Costs:

Equipment:
Pressure Washer - $100/day
Pickup Truck - $150/day
Water Truck - $600/day
Labor:
Laborer - $240/day
Supervisor - $320/day
Truck Driver - $320/day
Materials:
Water: $100/day

Subtotal: $850 + $880+ 100= $1830/day

Total: With Overhead/Profit (15%):$2100/day±

Assume production rate of cleaning a 6" wide x 4' long line in 10 seconds.
(0.2SF/second or 5,760 SF/8hr day)

$2,100/5,760SF = $0.36/SF

Removal Paint Costs:

Project	Year Bid	# of Bidders	Paint Removal Costs $/SF
Skyhaven Runway	2014	7	$1.34
Concord Taxiway B Phase 2/3	2014	5	$1.76
Concord Taxiway B Phase 1	2013	7	$1.96
		Average $/SF	$ 1.69

II. Assumptions on Frequency of Work:

- Type I/II Paint is applied every year with Type I beads. FAA P-620 specification allows the use of Type I beads if painting every 6 months. Annual painting used to simplify the calculation.
- Modified Type I/II is applied every year with Type I beads. FAA P-620 specification allows the use of Type I beads if painting every 6 months. Annual painting used to simplify the calculation.
- Type III paint and Type III beads require painting every 2 years.
- Modified Type III paint and Type III beads painting every 4 years. Washing is considered in the "in-between" years.

III. Present Value Formula (Reference FAA Order 5200.9, Appendix B)

Determined by $\mathbf{P}=\mathbf{F}/(1+\mathbf{i})^n$ where,

P = present value
F = future replacement cost (in current dollars)
i = the discount (interest) rate
n = the number of interest periods (years)